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THE CONTINUOUS SUPERSTRUCTURE OF THE MEMPHIS BRIDGE.

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General Features.—The Act of Congress authorizing the construction of the Memphis bridge specified that the main channel span should in no event be less than 700 ft. in length, nor the other spans less than 600 ft. each in length.

The board of engineer officers from the Engineer Bureau detailed to examine by actual inspection the locality where the bridge was to be built, determined that the channel span should be next to the Tennessee shore, but did not agree as to the proper length of this span. The Secretary of War decided that if the east pier of the bridge was placed at the low water-mark, the channel span might be 700 ft. in the clear, but

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proper guards would be required to guide tows in passing through the bridge ; at the same time he suggested that if this pier were placed 70 ft. back from the low-water shore line, which would bring the pier in about 9 ft. of water at the highest stage, these guards might be dispensed with.

The latter suggestion was accepted, and the plans which were submitted to and approved by the Secretary of War provided for a channel span 770 ft. long in the clear and two spans of 600 ft. each in the clear, these three spans crossing the entire navigable river. Adding to each span the estimated thickness of the piers at low water, the design called for one span of 790 ft. and two of 620 ft. each measured between centers of piers.

The arrangement which would have been most satisfactory to the Engineer would have been three equal spans of about 675 ft. each. If, however, one span of extra length was required, it would have been preferable to place it at the center, making this central span a cantilever structure, the cantilevers projecting from the ends of two heavy side spans. The arrangement required by the War Department, however, placed the long span next to the east shore, so that if this span was built as a cantilever span it was necessary to provide an independent anchorage on the Memphis bluff. This course was adopted.

The length fixed for the channel span was 790 ft., or 170 ft. more than either of the other spans. By projecting a cantilever 170 ft. long from Pier I (on the Tennessee shore), the distance between the end of this cantilever and Pier IV (on the Arkansas shore) was divided by the two other piers into three equal spaces of 620 ft. each. By making the central span a fixed span with continuous chords, and projecting a cantilever 170 ft. long from each end of this fixed span, there remained two spaces each 450 ft. long to complete the bridge, one of these being between two cantilevers, and the other between a cantilever and Pier IV. With this arrangement the bridge would consist of a central span 620 ft. long, of three 170-ft. cantilevers precisely alike, of two 450-ft. spans also alike, besides the anchorage span east of Pier I.

In order to simplify construction it was desirable to make the panels of uniform length throughout, and this required that the panel lengths should be common divisors of the lengths of the cantilevers, of the suspended spans and of the central span. No such common divisors existed for 170 ft. and 450 ft., but by shortening the length of

the cantilevers to 169 ft. 4½ ins. and increasing the length of the suspended span to 451 ft. 8 ins., 56 ft. 5½ ins. became a common divisor. The lengths were, therefore, slightly changed, and a panel 56 ft. 5½ ins. long was made the unit for the entire bridge, this panel being divided into two panels in the floor system. Each cantilever arm was divided into three panels, each suspended span into eight panels, and the central span into 11 panels.

As the bluff rose rapidly back of Pier I, a long anchorage span was not required, and it was thought best to limit it to such length that there would be no reversal of strains; it was made four panels or 225 ft. 10 ins. long.

The anchorage span consists of four panels; the channel span of 14 panels, three in each cantilever and eight in the suspended span; the central span of 11 panels; and the west span of 11 panels, of which three are in the cantilever and eight in the suspended span; the total number of panels is therefore 40, and the total length of the continuous superstructure is as follows:

Anchorage arm	225 ft.	10	ins.
Channel span	790 "	5	"
Central span	621 "	0½	in.
West span	621 "	0½	"
Total	2 258 "	4	ins.

The arrangement of these spans is given on Plate I.

As each truss panel is divided into two floor panels, there are 80 panels in the floor system. Moreover, the floor system is extended eastward on a viaduct of three floor panels beyond the anchorage pier, and a deck span of 12 floor panels reaches from the shore side of Pier IV to a special pier (V) built back of the shore line. The entire floor system of the bridge, therefore, consists of 95 panels, and is 2 681 ft. 9½ ins. long.

The lengths of the spans being fixed, the next thing to determine was the width. The principal limit in determining this was the length of the central span. In the matter of transverse stiffness the position of this span corresponded with the separate spans of a common bridge; whereas, the longer span by its cantilever construction was held rigidly at the ends. The central span being 620 ft. long, it did not seem wise to make the width between trusses less than 30 ft. This

corresponded with widths which have been adopted with good results in shorter spans. The channel spans of the Cairo Bridge are 518.5 ft. long and the trusses placed 25 ft. between centers, the ratio between length and width being almost exactly the same as between 621 ft. and 30 ft. A width of 30 ft. was adopted.

The next feature to determine was the depth of the trusses, and in determining this other considerations than economy of metal-work governed.

The difficulties of erection made it important to keep the dimensions within limits to which ordinary false-work could be adapted. The magnitude of the structure and its cantilever design made it important to use such proportions that vibrations would be reduced to a minimum. It was not thought best to make the depth at any part of the superstructure much more than two and one-half times the breadth of base. The breadth of base could not be increased without increasing the length of the piers, which would have added to the already excessive cost of the foundations. By fixing the depth of both the central and the suspended spans at one-eighth of the span and making all three of the cantilevers alike, the depth of the structure over each of the piers and for the whole length of the central span became 77 ft. $7\frac{13}{16}$ ins., and the depth of the suspended spans, 56 ft. $5\frac{1}{2}$ ins. These dimensions were adopted.

It was at one time proposed to make the central span in eight panels of greater length than those used elsewhere, but as the plans matured this seemed unwise, and a uniform panel length was adopted throughout.

The form of trusses adopted was the double triangular or double Warren girder. It was intended to erect the channel span without falsework, building out from either end, and this form of truss was thought to have advantages in the manner in which it sustained the upper chord from which the work would be done.

The floor system is suspended from the intersection points of the two systems of web members, and the upper chord is supported from the same points by struts.

As the depth of the cantilevers over the piers corresponds to the depth of the central span, while their outer ends correspond to the depths of the suspended spans, the chords are not parallel. The same may be said of the anchorage arm. In order to keep the floor panels

uniform, it was necessary to keep the points of intersection of the web members over the panel centers. This made the panel lengths of the upper chord irregular, but as these chords were formed of eye-bars the irregularity was not material.

The cantilever construction made it possible to bring the weight of the spans on each side of each pier together in a single point and transfer this weight directly to the center of the pier, instead of taking it nearer the edge of the pier as is always done with separate spans. This allowed the use of somewhat lighter piers than would otherwise have been needed, and the increased cost of the superstructure design over three equal separate spans was in a measure balanced by the decreased cost of the substructure.

The only span which is continuous from pier to pier is the central span, and provision had to be made at one end of this span for expansion and contraction. All other expansion was taken up by sliding joints at the ends of the cantilevers. As there are two sliding joints in the channel span and only one in the west span, there was a double chance to take up expansion in the chords and floor system of the channel span. For this reason the west end of the central span was fixed and the east end placed on expansion rollers.

Principal Details.—The general dimensions and form of truss having been adopted, it next became necessary to fix the character of the principal details. The American form of construction with pin connections was adopted from the first. The chords of the central span, being subject to reversals of strains from the action of the cantilevers, were necessarily both made stiff, and the same stiff bottom chords were necessarily extended out as the bottom chords of the cantilevers. The top chords of the cantilevers, being always in tension, were made of eyebars. As the east suspended span (in the channel span) was to be erected without falsework, the two halves being built out as continuations of the cantilevers, it was necessary that the bottom chord of this truss should also be made stiff for the greater part of its length, while the top chord, being in compression in the finished structure, was of course stiff. It was determined to sacrifice some material and to make the bottom chord of the suspended span stiff throughout, and to make both suspended spans (or intermediate spans as they were called on the drawings) with stiff chords throughout. The chords of the anchorage arm correspond to those of the cantilevers. The bottom

chord is therefore stiff throughout the entire length of the superstructure, and the only portions of the top chord which are made of eye-bars are in the anchorage and cantilever arms and in the end half panels of the central span, this special arrangement being adopted from the difficulties of packing a stiff chord into an eye-bar chord at the extreme ends of the span.

The stiff-chord provision undoubtedly adds to the lateral stiffness of the bridge and, to a certain extent, to its vertical stiffness. The sliding joints at the ends of the cantilevers are carefully fitted, and in spite of its cantilever construction the bridge is very free from vibration.

The lateral bracing is formed of diagonal rods attached to pin plates riveted to the chords, and so placed that the axial lines intersect at the center of each chord. The lateral bracing is adjustable, and is the only adjustable portion of the bridge. It would have been preferable to make it stiff, but the plan was adopted in conformity to the practice hitherto followed by the Chief Engineer of the bridge, he not being satisfied with the detail connections of any stiff system which he had worked out at the time these plans were prepared.

The transverse bracing is rigid throughout, and is made in the form of lattice frames, so as to stiffen, not merely the center of each post, but intermediate points above. The principle which led the engineer to adopt this form of bracing was his belief that the two trusses of a bridge should be made as nearly as possible a single truss. So far as the chords are concerned this cannot be done; but if the compression members of the web are united by stiff frames, they become in a large degree a single compression member of the full width of the truss, this single compression member transferring its strain to two chords at the top and two chords at the bottom. This principle of transverse bracing was followed throughout the whole superstructure. In the end posts of the intermediate and central spans and the posts of the cantilevers which carry the weight of the intermediate spans, the stiffening was carried further by extending portal plates down the sides of each separate post, thereby increasing the width of the posts and uniting the two sides with a stiff portal. In the case of the large vertical post over the piers, these portal frames were united with the floor beams below, so that the two posts form from top to bottom practically a single member.

The floor system consists of two stringers placed 8 ft. between centers, these stringers being riveted to the webs of the floor beams at each panel and half-panel point. At the full-panel points the floor beams are supported on short posts to which they are riveted, which posts rest directly on the pins. At the half-panel points the floor beams are suspended from the web intersections above.

Although the width between trusses is sufficient for a double-track bridge, the bridge, being designed but for a single track, has but two lines of stringers. The management did not feel justified, at the time the bridge was built, in bearing the additional expense which a double-track structure would have entailed. It should, however, be mentioned that the Memphis bridge, though designed for a single track only, is at least two and one-half times as strong as some important single-track bridges built less than 15 years ago.

The charter from the General Government required that the bridge should be adapted to the passage of vehicles and animals. This provision is met by making a tight floor 20 ft. wide; on each side of the floor are steel fences supported at the panel points, these fences being in fact lattice girders which carry the ends of the ties and so make practically four lines of stringers. The ties are planked longitudinally with 3-in. pine planks sized to 2¾ ins., and diagonally with 2-in. oak plank sized to 1¾ ins., this making 4½ ins. of solid planking. Between the rails the oak plank is laid longitudinally. It is doubtful whether this expensive highway floor will be much used.

In many respects the design of the superstructure may be criticised as not strictly economical. This is admitted, but such criticisms are ill-considered unless they include, not merely the metal in the superstructure, but all the material in the piers and masonry. The substructure of the bridge, which under the present design cost more than the superstructure, would have been rendered much more expensive by those changes which mere economy of superstructure design called for.

In the design attention was everywhere given to stiffness as well as to strain. This is a matter to which too little attention has been given, and which has often been overlooked in competitive designs. It is perfectly possible to design a structure in which no metal under any ordinary supposition will be overstrained, and yet without such overstrain vibrations can exist which would be utterly inadmissible. This

may occur in trusses of extreme depth, and also in structures with cantilever details in which loose fitting is permitted at expansion joints.

It was with a view to avoid vibrations as much as possible that stiff chords were adopted throughout, and that the principle was followed of uniting the compression members of opposite trusses as far as possible into single members. For the same reason, the sliding joints at the ends of the cantilevers were so carefully fitted that lost motion in these places practically does not exist.

While these ideas undoubtedly made the structure more expensive than a competitive design might have been, the engineer believes that the results fully justify his work; but in studying details these facts should be remembered.

*Special Details.**—With these conditions stated, attention is called to a few of the special details of the superstructure.

1. The stiff chords of the central span, including one full panel of the bottom chords of each adjoining cantilever, were made with four webs. This form of construction was adopted for two reasons. First, to reduce the thickness of the metal and so to reduce the lengths of the rivets in the splices. With the present arrangement the maximum length of rivets is $3\frac{5}{8}$ ins. between heads, and the larger part of the rivets are in double shear, the splices being balanced on the two sides of each web, this being the condition under which the rivets are least likely to get loose and least likely to cause trouble if they become loose. The second object was to reduce the bending strains on the pins; the connections with the web members are all made in the narrow spaces between the outside and the interior webs, so that the pins, by which the whole horizontal strains are transferred to the chords, are supported at four points, and the unsupported length is reduced to a minimum. The objection to high theoretical bending strains in pins is not so much the danger to the structure from the failure of the pins as the fact that by the distortion of the pins the strains may be distributed unequally among the several pieces attaching to them. With the arrangement adopted here, this danger is reduced to a minimum.

The four-web chords are confined to 10 full (20 half) panels of the top chord of the central span, to 11 full panels of the bottom chord of the same span, two full panels of each cantilever arm and two full panels

* The *general* plans of the superstructure are given on Plates II, III, IV, V.

of the anchorage arm. Two-web chords were used in the remaining bottom panels of the cantilever and anchorage arms and throughout the whole length of the suspended spans. In the bottom chords of the suspended spans the rivets became objectionably long.

The sections of the stiff chords were generally made in full-panel lengths, 56 ft. 5½ ins. long, the riveted joints being placed midway between the panel points and over the intermediate points; the only exceptions to this rule were in the upper chords of the intermediate spans and the lower chords of the cantilever arms and anchorage span. The details of the riveted joints are given on Plate X.

2. The shortness of the anchorage arm insures the connection being always in tension and never in compression. The details of the anchorage are given on Plate VI. The masonry of the anchorage pier is built on a platform of I beams. Under this platform are placed steel washer-plates with conical sockets through which the anchor rods pass, the weight being transferred to the anchor rods on conical counter-sunk heads. The anchor rods are built solid into the masonry, and run through steel plates on top. The top of the rod is turned down, and screws of two different diameters are cut on it. The nuts on the lower screw, 3½ ins. in diameter, screw up against the plates on top of the masonry, thus taking up any possible slack in advance of strain. The upper smaller screws, 3⅛ ins. in diameter, carry two nuts, besides a check nut on top, and these two nuts hold between them the cross-blocks which carry the pin on which the outside anchor rods attach. Under each truss there are 16 rods in the masonry, these rods connecting with eight blocks which carry the single pin on which four anchor bars connect. These anchor bars are simply flat bars of steel with pin holes at top and bottom. After the adjustment of the structure, folding wedges were placed between the steel plate and the blocks and tightened up so as to prevent any possible horizontal bending strain on the anchor rods. On the center of the pier was placed a tetrapod of steel, the four corners of which were anchored to the masonry and the apex of which fits into a guide at the center of the end floor beam, the connection being such that no weight can be thrown upon it, but a full horizontal stiffening is obtained.

The general arrangement of the anchorage is such as to place all adjustable or movable parts in the open air above the masonry in plain sight, there being no unexposed portions and no iron-work

buried in chambers, the only iron out of sight being the long rods and the I beam platforms, which being buried solid in Portland cement are protected from oxidation, while there is a large excess of material in the rods.

3. The superstructure and moving load throw on each of the two points of support on Piers I, II and III a weight of about 2 000 tons, this weight, however, being thrown directly over the axis of the pier. To distribute this weight properly on the masonry requires an area of about 100 sq. ft. and a sufficient height between the masonry and the chords of the superstructure to distribute it with some degree of uniformity. On Piers I and III the bearings are fixed. They are shown on Plate VII. In each instance the weight is transferred first to a 14-in. pin passing through the center of the chord. The three posts, one vertical and two inclined, rest on this pin, being made with semi-circular pin bearings at the ends, no pin plates passing around the pins, this arrangement being adopted partly for convenience in erection and partly because the weight always carried here is so great that nothing approaching to tension can ever exist. This 14-in. pin rests on a steel casting, cast with ribs placed directly under the bearings of the posts on the pin. The inclined posts are two-web posts, and the vertical posts four-web posts, but they are so packed that the whole weight is transferred to six ribs in the castings. The steel casting rests on two iron castings which are packed with long bolts and locked together with a grooved steel plate between them. These two castings rest again on four castings, which are locked together in the same manner at the center. The whole was fastened together by turned bolts passing through drilled holes. The actual weight of each pedestal casting between the pin and the masonry is about 45 tons. The center of the 14-in. pin is 9 ft. 10 ins. above the masonry, which brings the top of the stringer of the bridge 13 ft. above the masonry.

4. On Pier II the bearing, which carries the same weight as those on Piers I and III, had to be made an expansion bearing to allow of the expansion of the central span, temperature alone here representing an expansion of about 8 ins. It is shown on Plate VIII. The piers are slender and the expansion great; it was therefore deemed necessary to provide a joint which would move with the least possible friction and which should not be liable ever to become clogged or stopped by the collection of dirt. The joint must also be so arranged that the struc-

ture would be held laterally and the motion limited longitudinally. It was therefore determined to use rollers 15 ins. in diameter and to make these segmental rollers of a pattern resembling the European practice, the rollers being placed 6 ins. between centers.

Each expansion bearing as constructed consists, first, of a steel casting precisely similar to those used at the fixed end. This steel casting rests on a bolster composed of a horizontal top plate, then of eleven 12-in. I beams running transversely, of a second horizontal plate, of sixteen 12-in. I beams running longitudinally, and of a third and thicker horizontal plate, the lower surface of which is polished smooth. It had originally been intended to make this bolster of two steel castings with a planed steel plate between them, and this arrangement would have been preferred; but the delays in getting the castings and the uncertainty of securing the finished product in time, made it necessary (after three castings had been made and rejected) to change the plan.

Under the bolsters came the rollers. The rollers are in two lengths and are separated by two steel guide-plates, one of which is built in between the polished bottom plates of the bolster and the other between the iron castings below. These serve as the transverse guides. There are 30 rollers in each joint, 15 on each side of the central guides. The rolling surfaces of these rollers are polished, and each roller has two holes drilled completely through it, through which pass turned rods, so that the rollers on one side of the center must always work with those on the other, while the distances between the rollers are kept constant by two side-plates drilled to fit the rods, the rods being held in place by nuts outside the side-plates. The upper side-plates are made with hooked ends, which, striking against the ends of the lower side-plates, limit the possible motion of the rollers and prevent any possible overturning.

Under the rollers is the bearing plate (commonly called the rail plate). This is of the pattern which the Engineer has used universally for the last 10 years. It is formed of T rails riveted on a plate below, the tops of the rails being about $\frac{1}{4}$ in. apart and the top surfaces planed and polished. This arrangement makes a stiff surface for the rollers to roll upon and provides adequate means for cleaning. The rail plates are in two parts, divided by the center plate which guides the rollers.

The motion of the top bearing is further limited by a lock plate which is fitted over the lower guide plate, the upper jaws of which would strike the edges of the top bearing plate before a motion could occur which might cause the top plate to slide on the rollers.

Under the rail plates are the castings, which bear directly on the masonry and are like the lower sections of the fixed end castings.

The result of this arrangement is a very sensitive and very powerful expansion bearing. For convenience of observation it was fitted with vernier scales, and the record which has been kept of the motion so far, indicates that this bearing works practically without friction.

5. A somewhat different form of support was used at the end of the intermediate span over Pier IV. This is shown on Plate IX. Here, also, the weight is distributed on the masonry by iron castings, and the weight is transferred to the iron castings through a pin on a steel casting; but the pin is placed below the level of the chord, the whole weight being transferred by a small upright support, which also holds the floor beam. While this works fairly well, it is not as satisfactory a detail as the other bearings. It was adopted with a view to keeping the construction of this particular panel point as nearly uniform as possible in the four places where it occurs, this supported upright taking the place of the suspended uprights at the other three points.

6. The expansion between the cantilevers and the suspended spans is taken up by sliding joints in the top and bottom chords, the long suspender swinging. No special addition was made to this suspender in consequence of this swinging motion, the extra strain which can possibly be produced in this way being less than that which is usually produced in horizontal eye-bars by their own weight. The sliding joint in the bottom chord is placed in the last panel of the cantilever. The sliding joint in the top chord is placed in the first panel of the suspended span. As the end web members of cantilever and suspended spans are parallel compression members, both of these sliding joints come where no strain exists.

The sliding joint in the bottom chord is shown on Plate XII. It slides between polished steel surfaces with a play of only $\frac{1}{32}$ in. This joint is placed near a floor beam, and the lateral system of the cantilever arm ends at this floor beam, which forms the lateral strut. The lateral system of the suspended span ends on the other side of the sliding joint, there being an independent strut to hold the two chords in

position; this strut was put in after the erection of the superstructure, the pin holes being reamed in position. There is no observable lost motion at this joint. The top lateral strains are transferred at the ends of the suspended spans to the bottom chord by the portal bracing, and there is no lateral system in the top chord of the end panels of the suspended spans. The sliding joint in the top chord is made, therefore, simply an oblong pin hole between two sets of stiffened tension members. The same oblong pin hole was used in the bottom chord joint, but principally for necessities of erection.

7. The large expansion existing at the ends of the suspended spans made some special expansion arrangement necessary in the connection between the stringers and the floor beams. An ingenious arrangement to accomplish this end was designed by Mr. Ralph Modjeski, Assistant Engineer, and is shown on Plate XII. It dispenses entirely with a long sliding surface and supports the end of the stringer perfectly.

8. As the end of the anchorage arm consists only of tension members, it was difficult to make a satisfactory form of portal which would at once resist vibrations and have the substantial appearance which seemed important in the most conspicuous part of the bridge. The result was accomplished by making a stiff frame, entirely independent of the tension members, consisting of posts placed between the inclined eye-bars of the end panels, these posts being connected by a stiff strut at the center, and the rectangular panel above divided by stiff diagonals. This stiff frame is attached to the pins of the truss, but the pin holes in the stiff posts are made 1 in. larger than the diameters of the pins, so that the tensile strains should not be disturbed.

Loads.—The views of the Chief Engineer have long been opposed to proportioning bridge superstructures for precise wheel-base loads, these precise loads being always those of a special locomotive, either actual or assumed, and subject to constant change. The superstructure of the Memphis bridge is proportioned in accordance with the practice now followed by that Engineer, the load per foot on a length of 20 ft. being taken as twice the load per foot on a length of 120 ft. and upwards, and the load per foot being increased by 1% for each foot in length less than 120 ft. The excess variation in web members, being the difference between the strains produced by a moving load and by a fixed load of equal intensity, is taken on a basis one-half greater than the uniform moving load. In the case of the Memphis

bridge the unit load was taken at 4 000 lbs. per foot of track, and the wheel-base load on 20 ft. was consequently 8 000 lbs. per foot of track, while the stringer load, the panels being a little more than 28 ft., was taken ($4\,000 \times [1 + 0.92] = 7\,680$) at 7 680 lbs. per foot of track. These weights were used in calculating the live loads given on the strain sheets shown on Plates XIII to XVII inclusive.

In the central span the dead load was assumed in the strain sheet at 4 000 lbs. per linear foot of truss, or 8 000 lbs. per linear foot of bridge, being just double the assumed live load. In point of fact, the actual weight of this span is 8 300 lbs. per linear foot, exclusive of end posts, which stand directly over the piers. This excess of weight amounts to less than 4%, and is no greater than the difference in weight between the kind of floor used on this bridge to accommodate highway traffic and the usual railroad floor.

In the intermediate or suspended span the dead load was assumed at 5 400 lbs. per linear foot. In point of fact it is 5 660 lbs., or a little less than 5% in excess of the calculated weight, the actual difference being almost exactly the same as in the central span.

In the anchorage and cantilever arms no fixed rate of dead load was assumed, but the strain sheet was made by assuming the estimated weights of the different members as concentrated at the separate panel points, these concentrations, of course, being greatest nearest the piers. In every case the weight of a tension member was supposed to be carried at the upper end of that member, and the weight of a compression member to be carried at the lower end of that member, this, of course, only applying to the resultant portion of that weight which moved in the direction of the axis of the member. The panel point loads are given on the strain sheets.

The upper lateral system is proportioned to resist a horizontal pressure of 300 lbs. per linear foot of bridge. The bottom lateral system is proportioned to resist a horizontal pressure of 600 lbs. per linear foot. In both instances the whole horizontal pressure is treated as a moving load. This differs from the usual practice; but the allowance made for moving loads is inadequate rather than too great, as it is among the possibilities that when half of a span is exposed to a wind pressure in one direction, the other half may be exposed to a wind pressure in precisely the opposite direction.

No allowance is made in the strain sheets for the disturbances of

the distribution of weight by wind pressure. A simple calculation showed this to be unnecessary. The lateral pressure on the top chord will exercise its greatest disturbing effects in the central span. Taking this pressure at 300 lbs. per foot, multiplying it by the depth of the truss, and dividing it by the distance between truss centers, we have a resultant of 800 lbs. as the possible increase of weight on one truss due to this cause, this being 20% of the estimated dead load and 13% of the estimated total load. If we take a wind pressure of 400 lbs. per linear foot applied on a train of maximum weight at an average elevation of 8 ft. above the rails, the effect of this wind pressure is to move the center of gravity of the moving load 0.75 ft. from the center of the track ; as the center of the track is 15 ft. from the center of each truss, this increases the moving load carried by one truss 5% and diminishes that carried by the other 5%, thus actually increasing the weight thrown on one truss 100 lbs. Taking these two disturbances together, the total extreme weight which can be thrown on one truss amounts to 900 lbs. per linear foot or 15% above the assumed calculations.

No addition was made to the chord sections to provide for lateral strains. The assumed lateral force on the bottom chord is 600 lbs. per linear foot ; the assumed total weight carried by each truss is 6 000 lbs. per linear foot ; the depth of the trusses is 2.6 times the distance between centers of trusses, so that the strain thrown into the chords by the lateral system is equal to 26% of that thrown in by weight. In the top chord the effects of the lateral strain would be one-half this amount, or 13 per cent.

As the effect of the disturbance in weight by wind pressure is to increase the tension in the leeward bottom chord 15%, while the effects of the strain in the lateral system are to increase the tension in this chord by 26%, the total effect is an increase of tension of 41% in the leeward chord and a corresponding reduction of tension on the windward chord. In the top chord the effects are much less. With the unit strain allowed these strains are well within safe practice.

Proportioning of Materials.—The entire superstructure of the Memphis bridge is of steel, and it was all worked as steel, the rivet holes being drilled in all principal members and punched and reamed in the lighter members.

The tension members were proportioned on the basis of allowing

the dead load to produce a strain of 20 000 lbs. per square inch, and the live load a strain of 10 000 lbs. per square inch. In the case of the central span, where the dead load was twice the live load, this corresponded to 15 000 lbs. total strain per square inch, this being the greatest tensile strain.

The compression members were proportioned on a somewhat arbitrary basis. They were generally designed so as to make them of symmetrical section, and almost always so as to make them symmetrical about the line dividing the least transverse dimension. No distinction was made between live and dead loads in proportioning compression members. A maximum strain of 14 000 lbs. per square inch was allowed on the chords and other large compression members where the length did not exceed 16 times the least transverse dimension, this strain being reduced 750 lbs. for each additional unit of length. In long compression members the maximum length was limited to 30 times the least transverse dimension, and the strains limited to 6 000 lbs. per square inch, this amount being increased by 200 lbs. for each unit by which the length is decreased.

The form of the structure is such that reversals of strains occur in the web members of both central and intermediate spans and in the chords of the central span. Wherever this occurs the member was proportioned to resist the sum of compression and tension on whichever basis (tension or compression) there would be the greatest strain per square inch; and, in addition, the net section was proportioned to resist the maximum tension, and the gross section to resist the maximum compression.

The floor beams and girders of the floor system were calculated on the basis of the moment of inertia, the strain being limited to 10 000 lbs. per square inch in extreme fibers. In the floor beams the rivet holes in cover plates and flanges were deducted. In the stringers, where there are no cover plates and pains were taken to avoid rivet holes in the flanges, the gross section was used.

The rivets, all of which are of steel and in drilled or reamed holes, were proportioned on the basis of a bearing strain of 15 000 lbs. per square inch, and a shearing strain of 7 500 lbs. per square inch, and special pains were taken to get the double shear in as many rivets as possible. This was the requirement for shop rivets. In the case of field rivets, the number was increased one-half. In the splices of the

chords of the central span, which is strained both in tension and compression, but in which the faced ends of the several sections were carefully fitted to close bearings, the number of rivets was based on the sum of the two strains; but the increase in the number of field rivets over what would have been required for shop rivets was made 25 instead of 50 per cent. The chords of this span are of uniform section throughout, and all the riveted joints are alike.

The pins were proportioned on the basis of a bearing strain of 18 000 lbs. per square inch and a bending strain of 20 000 lbs. per square inch in extreme fiber, the diameters of the pins being never made more than one inch less than the width of the largest eye-bar attaching to them. Special pains were taken in packing the pins to divide the strains from the members on one side among those of the members on the other side, the general principle being to take the strain in each eye-bar by itself, and consider that one-half of it goes into the eye-bar on either side leading in the other direction. With this system of packing, the bending strain in extreme fiber is a matter of little importance.

The weight on the rollers of the expansion joint on Pier II is 40 000 lbs. per linear foot of roller, or 3 333 lbs. per linear inch, the rollers being 15 ins. in diameter.

Material.—As the sections of the superstructure were necessarily unusually heavy, and the strains from dead load were greatly in excess of those from moving load, it was thought best to use a slightly higher steel than is now generally used for lighter structures, and to work this steel without punching, all holes being drilled. A somewhat softer steel was used in the floor-system, lateral connections and other lighter parts.

The details of the requirements both for steel and manufacture are given in the Specifications dated January 4th, 1890, which accompany this paper, marked Appendix A. The principal requirements which were to be obtained as the results of tests on samples cut from finished material were as follows :

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in....	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in....	69 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in.....	40 000	37 000	30 000
Minimum percentage of Elongation in 8 ins.....	18	22	28
Minimum percentage of Reduction at Fracture..	38	44	50

A piece of each sample bar was also required to be bent 180° and to close up against itself without showing any crack or flaw on the outside of the bent portion.

The specifications as originally drawn provided for a preliminary test on a ¾-inch round bar, and allowed the steel to be made by either the open-hearth or Bessemer process. So much difficulty was experienced, however, in getting a satisfactory Bessemer steel, that the requirements for the preliminary test on the round bar were so much reduced as to amount to little, and all steel was required to be made by the open-hearth process. These requirements appear in the supplemental Specification dated May 6th, 1890, which is attached to this paper and marked Appendix B.

After the first tests had been made on full-sized eye-bars, it appeared expedient to adopt for this purpose a steel midway between the high grade and medium steel of the former specifications, and steel of the following requirements, denominated eye-bar steel, was prescribed thereafter :

	Eye-Bar Steel.
Maximum Ultimate Strength, lbs. per sq. in	75 000
Minimum Ultimate Strength, lbs. per sq. in	66 000
Minimum Elastic Limit, lbs. per sq. in	38 000
Minimum percentage of Elongation in 8 ins	20
Minimum percentage of Reduction at Fracture	40

These requirements were provided for in a supplementary Specification dated January 1st, 1891, which accompanies this paper and is marked Appendix C.

The results showed that this material was thoroughly satisfactory for most of the purposes for which it was wanted. It was specially so in the 10-in. eye-bars which form the tension members of the anchorage and cantilever arms and of the webs of the central span. The smaller eye-bars which suspended the intermediate points did not give quite as satisfactory results. Tests were made of 56 full-sized eye-bars, and the results are given in Appendix D, attached to this paper. An inspection of this list shows the excellent character of the 10-in. bars.

Owing to the difficulty of getting satisfactory small bars, the sizes of the suspenders which support the floor beams at the intermediate points were increased from 6 x $1\frac{3}{16}$ ins. to 7 x $1\frac{5}{16}$ ins., and from 6 x $1\frac{1}{8}$ ins. to 7 x $1\frac{3}{16}$ ins., and a softer steel was accepted than the specifications required. A corresponding change was made in the diagonal eye-bars of the intermediate span last manufactured, the width of these bars being increased from 8 to 9 ins., with no other change.

The results of these tests and observations on other work seem to indicate that in large bars a comparatively high steel gives the best results, and, if they are well annealed, is quite as soft as it is desirable to have. On the other hand, in small bars as low a steel as is consistent with sound ingots is probably the best material, but it must be remembered that in trying to get a very soft and ductile steel the chance of blow-holes and other unsound features is increased. For one other reason the use of a higher steel for heavy eye-bars seems wise, as where heavy bars are used it may generally (though not always) be assumed that the strain due to live load is small in proportion to that due to dead load.

In the west intermediate span, being the one which was built by A. & P. Roberts & Co., the riveted members were made of medium steel throughout, the work being punched and reamed. In the other intermediate span the requirements of the specifications were adhered to.

Contractors.—The contract for all the material for the superstructure was originally taken by the Union Bridge Company, and about five-eighths of the whole was actually manufactured by them at their shop at Athens, Pa., the remaining three-eighths being made at various other places. The largest contract placed elsewhere was with A. & P. Roberts & Co., who built one of the intermediate spans (as well as the deck span west of Pier 4, except the eye-bars), the Union Bridge Company relinquishing this portion of their contract and a new contract being made with A. & P. Roberts & Co.

The other shops generally did their work as sub-contractors for the Union Bridge Company, though in some cases special things were ordered direct.

The actual weights and percentages manufactured by the different shops were as follows, the deck span west of Pier IV being included in this statement:

	Pounds.	Percent.
Union Bridge Co.	10 432 020	63.9
A. & P. Roberts & Co	3 113 250	19.07
Elmira Bridge Works	1 127 584	6.94
Lassig Bridge and Iron Works	806 617	4.94
Scaife Foundry and Machine Co.	423 963	2.59
Keystone Bridge Co	310 585	1.90
Pittsburgh Steel Casting Co.	61 935	0.37
New Jersey Steel and Iron Co	40 712	0.25
Pittsburgh Bridge Co.	7 171	0.04
	16 323 837	100.00

The work manufactured by the Elmira Bridge Works consisted principally of web members of the central and intermediate spans.

The Lassig Bridge and Iron Works furnished the four vertical posts and portals at the ends of the central span besides some other web members.

The Scaife Foundry and Machine Company furnished the large castings on the piers.

The Keystone Bridge Company furnished the anchor rods within the masonry of the anchorage pier, a quantity of eye-bars and the bearing plates upon the rollers on Pier II. The Pittsburgh Steel Casting Company furnished the steel castings over Piers II, III and IV. The 15-in. expansion rollers, which were very finely finished, were made by the New Jersey Steel and Iron Company.

All the steel used in this bridge (except a small portion of that manufactured by A. & P. Roberts & Co.) was made by Carnegie, Phipps& Co., Limited (now the Carnegie Steel Company). It was all open-hearth steel, and a large portion of it was made in basic furnaces.

The work was manufactured in the several shops named, according to working plans prepared by the engineer of the bridge, and shipped to the bridge site ready for erection.

Erection.—A contract was executed on the 10th day of May, 1890, with William Baird and Andrew Baird, comprising the firm of Baird Brothers, for the erection of the superstructure for a fixed sum, this sum being divided between the several spans. The contractors received the material as it arrived, took responsible care of it and erected it in position. The requirements which governed this erection are contained in the specifications which form Appendix A attached to this paper.

All of the bridge except the suspended span between the cantilevers of the channel span was erected on falsework. This suspended span was projected from the ends of the cantilevers, connected at the center and then swung free.

Bents were placed under the panel points of the trusses. Each bent had nine posts, the center post and the third post from each side being plumb throughout, the other posts battered. All posts were of 12 x 12-in. timber, and the bents were built in three stories. The falsework was braced longitudinally by girths at each story, the girths at

the ends being bolted to the stone piers. Each bent rested on 18 piles, these piles generally being cut off at elevation 205 or 11.2 ft. below high water. On the top were placed 20 lines of stringers, four at the center and eight on each side, to carry the traveler tracks.

This falsework terminated at the proper level to receive the bottom chord. Four lines of rails, two on each side, were laid to carry the traveler, which was made long enough to reach over one and one-half full panels, or three floor panels, being composed of four bents.

The material for the anchorage arm and the adjoining cantilever was received on cars at the top of the bluff east of Pier I. All other superstructure material was received in a yard under the bluffs, where it was stored and subsequently handled by barges.

Erection was begun on the east shore, and the traveler was set up on the ground back of Pier I; on the 31st of March, 1891, this traveler was completed and ready to begin work, the false-work at that time only extending as far as Pier I. The first piece of bottom chord section was placed on the 3d of April, and the anchorage arm was virtually completed on the 6th of May. Meanwhile the false-work had been extended westward to the end of the east cantilever arm, and the erection of this cantilever arm was practically completed on the 20th of June, though the false-work and traveler were maintained in this position and some further work was done on the last panel as late as July 31st.

The driving of the false-work for the central span was begun in July. The work was begun west of Pier III, the piles for six bents being driven west of that pier. The two westward bents were placed close together, and on top of these were erected derricks by which the material was lifted from barges. The entire false-work between Piers II and III was completed by the end of August. This false-work was placed in the middle of the Mississippi River immediately after the flood season. It was very heavy and expensive, the piles generally being from 90 to 100 ft. long and driven about 20 ft. in hard sand below the bottom of the river.

When this false-work was completed the traveler which had been used on the east side was taken down and set up on the false-work. It was in itself a pretty large structure, standing 97 ft. above the track on which it ran and nearly 200 ft. above the surface of the water.

This traveler when completed consisted of four bents, only three of which had been used on the east side.

Two derricks were set up at the west end of the false-work west of Pier III, and all the members of the central span were taken by barges from the material yard under the bluff on the east side of the river to the west end of the false-work, where they were raised by the derricks to the floor level, there placed on push-cars and carried out to the traveler by which they were put in position. Everything was handled by steam, the engines being placed near Pier III.

The erection began with the placing of the first piece of the bottom chord on September 13th, 1891, the castings and the expansion bearing on Pier II having been previously erected. The entire bottom chord was put together and riveted up, the riveting being generally done by air riveters carried on a special small traveler. These riveters were of two patterns, one designed by Mr. Charles Vogel under the direction of the Chief Engineer, and the other, by the Allen Riveting Machine Company, of New York.

On the 25th of September the erection of the web members began. The erection was begun one panel east of the center, and the traveler moved westward. On the 3d of October the end posts at the west end of the span were placed; the traveler was then moved eastward, and on the 11th of October the end posts at the east end were placed. The span was swung on the 15th of October, 1891. The erection from the placing of the first chord section to the swinging of the span occupied 32 days.

This span, the total weight of which is 5 122 252 lbs., is believed to be the heaviest and longest span that was ever erected on false-work. A single member, the section of top chord between panel points U1 U3, weighed 61 944 lbs.

On the completion of the erection of this span the false-work was driven for the cantilever which projects from the east end of it, and this cantilever was also raised with the traveler, it being completed on the 31st of October.

The traveler was then moved to the west end of the span; the false-work was removed from under the east projecting cantilever and the eastern end of the span, to the span between Piers III and IV. On the 24th of November the western cantilever was completed. On the 7th of December the entire false-work was finished so that the erection of

the suspended span reaching to Pier IV could begin. The bottom chord of this span had to be riveted before it was swung, but the connections were all made by December 16th.

This completed the erection of the continuous superstructure except the suspended span over the channel. The traveler which had done its work was now taken down and the false-work removed.

The actual erection of the last suspended span, the only portion of the Memphis bridge which was erected without false-work, was begun on the 9th of February. A traveler of simple character, which consisted of a platform resting on the top chords and carrying two derricks guyed to a stiff frame, was set up at the east end of the west cantilever of this span (this being the cantilever which projects from the east end of the central span). The material was taken out in a barge under these derricks and lifted into position.

The weight of this suspended span was so great that the chief engineer hesitated about employing the adjustable wedges which have been used on similar structures at the connection between the cantilever arm and a suspended span. Oblong holes, each carrying two pins, were placed at the sliding joints (see Plate XVIII), and by placing adjustable wedges between these pins the position of the end of the projecting span could have been raised or lowered, or the span could have been moved backward. The engineer, however, decided to erect the west end without any adjustment and the east end with a hydraulic adjustment, and to make the connection between the bottom chords with eye-bars, which, acting as a toggle joint, could take up variations of length. The engineer now admits that this was an error in judgment. Wedges could have been used to better advantage than the fixed connections at the west end or the hydraulic connection at the east end. The hydraulic connection at the east end was used only in the bottom chord, a double wedge arrangement being used in the top; the double wedge is not as good as the single wedge.

After the cantilever arms had been built out, the opening between them, which had been carefully triangulated, was measured direct with a steel wire. Computations were made showing the changes in length of the members of the central span, the anchorage span and the cantilever arms, resulting from the building out of the half spans of the intermediate span. The positions of the ends of the cantilever arms at the adjustment point under that condition were then calcu-

lated, as well as the form of the half span when built out. These calculations gave data for fixing the distance between the adjustment pins of the first half span (the west one) that was built. The distance between these pins, which determined the position of the free end of the half span when built out, was fixed by stationary castings (shown in Plate XVIII); these were made in two parts for convenience in handling. After the erection of the half span had been commenced, no change could be made in its final position.

When calculating the final position of the half span, it was assumed that the erecting outfit of traveler, engines, lines and scaffolds would remain on it until the span was swung. This was an error; the unusual weight of the span insured much difficulty in swinging, and it should have been assumed in the first place that all appliances not absolutely necessary in swinging the span would be removed as soon as the half spans were built out. They were removed, and the free end of the west half span, after their removal, was 5 ins. above the elevation intended; this added materially to the subsequent difficulties.

The adjustment pins and castings for the west half-span were placed February 9th and 12th. Erection was proceeded with and the half span erected to within one panel of the center of the span during the next 20 days. The traveler used for this purpose was then removed, and the erection engine, lines, etc., run back to the end of the cantilever arm.

The distance fixed between the adjustment pins had been based on calculations of extensions or contractions due to the increased strain resulting from the building out of the half spans; these computed changes in length were applied as corrections to the measured distance across the opening between the cantilever arms. The corrections to the upper chord opening depended on computed changes in length of chord members for a distance of 1 863 ft.; the corrections to the lower chord opening depended upon computed changes in length for a distance of 1 411 ft. A slight error in the assumption as to loading would produce an appreciable difference in the total extension or contraction in these distances; moreover, the members were in the main riveted members with heavy splice plates, tie plates and lattices, all of which increased the average cross-sections, so that with a correct strain sheet the calculated changes in length might be to a considerable extent in-

exact. It was therefore thought necessary to provide for a small adjustment for the east half span.

Wedges (shown in Plate XVIII) were made for the upper chord adjustment. They provided for a total variation in distance between pin centers of only 1 in. Some small variations from plan dimensions reduced this range to about $\frac{7}{8}$ in.

The removal of all appliances from the west half span not only caused the free end to rise above the elevation intended, but, by reducing the strains in all members, caused the free end of the upper chord to be about 1 in. west of the place expected. On the other hand, the time required for erecting the span was greater than had been expected, so that the connection at the center was made later in the season and at a higher temperature than had been assumed. These two changes in condition almost balanced each other.

It was expected that the wedges would be immovable after the half span had been built out its full length; they were to be used, however, for a final adjustment after the half span had been built out half its length. Before beginning the erection of the half span, the distance across the opening was again measured and the wedges placed at nearly mid-position, the measurement having checked previous measurements and computations within a small part of an inch. After the wedges had been placed and the erection of the half span commenced, the adjustment was not changed until the span had been released at the adjustment points at the west end.

When an attempt was made to move these wedges, the double wedge was found defective. One of the wedges would move first; the immediate result was a great increase of pressure on the other wedge applied at its small end; this fixed it in place, and as the screw was turned to continue the withdrawal, the movement of the first wedge continued until some means were used to prevent its movement.

For the lower chord adjustment at the east end of the span a hydraulic jack (Plate XVIII) was provided for each truss. Each jack had a plunger 14 ins. in diameter, with a stroke of 3½ ins. One force-pump was provided for operating these jacks; it was of special design and very simple in construction. The ordinary leather cup-packing proved inadequate and was replaced by soft lead. The adjustment in the lower chord was simply the thrusting out of the hydraulic jacks to the proper distance, to give the end of the half span, when built out, the

same elevation as the end of the west half span, already built. The stroke of the jacks was not enough for this, but this was provided for by placing crescent-shaped fillers in the elongated pin-holes between one of the pins and the webs of the chord. When the half span was built half its length, the jacks were used to increase the distance between the adjustment pins ¼ in. With this adjustment the limit of the capacity of the pump was reached; and as the erection proceeded, this half span, like the west one, became unadjustable. When the half spans met at the center they were so nearly the same elevation that little difficulty was met in driving the center pins of the upper chords which closed the span and completed the connection between the upper chords and the web systems.

To supply the place of the end adjustments ordinarily provided for swinging the span, the Chief Engineer decided to depend mainly on expansion by temperature to extend the upper chord, and on a toggle joint to shorten the lower chord, so that the adjustment pins could be withdrawn. For one full-truss panel of the lower chord there were substituted two lengths of eye-bars connected to adjoining sections of bottom chord by temporary pins, and to each other by short coupling bars. A short vertical rod 2 ins. square, having a nut at the lower end and an eye at the upper end, passed between each pair of coupling bars and through a washer which took bearing on the lower edge of the coupling bars. The toggle joint was completed by lifting on the 2-in. square rods. The eye-bars and couplings were planed to permit the insertion of the riveted lower chord sections after swinging the span, the top-flange angles being removed and riveted back again after placing. The arrangement of the bars is shown on Plate XIX. The eye-bars were called the toggle bars; the joint at center was called the toggle joint, and the rods by which the toggle joint was pulled up were called the toggle rods.

As the ends of the half spans were too high, the opening in the lower chord between the ends of the riveted sections (one section at the center being left out), when the joints in the upper chord were just brought into bearing, was nearly 4 ins. less than the length of the closing section. It was necessary to raise the toggle joint 3 ft. before the toggle bars became taut. By loading the adjoining cantilever arms the lower chords were compressed so that the toggle bars became taut when the toggle joint was lifted 1¼ ft.

The erection of the east half-span ready for the closing sections was completed April 8th; the traveler and all superfluous material were removed; a derrick was erected on the end of each arm to handle the closing sections. The season was well advanced, and for several days the temperature had been too high to close the upper chord sections, if all preparation had been made; but cooler weather came opportunely, and at 9 A.M. of April 10th they were inserted, with an opening of only $\frac{1}{16}$ in. more than required.

During the next three days the inclined rods (Plate XIX) for lifting the toggles were placed; in addition, two pairs of heavy triple blocks, rove with manilla line 2 ins. in diameter, were placed in each truss, connecting the upper and lower chords at the center of the span, each pair of blocks having a capacity of 25 tons. The derricks were taken down, and all was in readiness to swing the span; but the weather became cold when heat was wanted.

During the swinging of the span changes in strain causing changes in length must occur. The total shortening thus caused in the upper chords amounted to about $4\frac{5}{8}$ ins. The distance between the fixed points on Piers I and III was 1 411 ft. $5\frac{1}{2}$ ins. The change in length for 1° Fahr. was 0.0095 ft. To produce a change in length of $4\frac{5}{8}$ ins. required a change of 41°. The top chord at the center of the intermediate span became closed at 56°. A temperature of 97° was necessary to release the adjustment pins in the upper chord. This natural temperature could not be had, and various means were tried to swing the span at a lower one, all tending to increase the length of the upper chord.

During the several days of cool weather which followed the connection of the top chords at the center of the span, the cantilever arms between Piers I and II were loaded with timber, rails, locomotives, etc. to about 6 000 lbs. per linear foot. The toggle rods were screwed up daily and the adjustment pins watched closely, but there was no sign of loosening. The resident engineer, Mr. Alfred Noble, adopted the expedient of heating the upper chord of the intermediate span with steam. A $1\frac{1}{2}$-in. pipe was placed in each chord for the entire length of the span. Canvas was placed under the pipe on the lacing, to retain the heated air in the chord; on the 19th of April steam from the locomotives was turned on the pipes, the toggle rods were screwed up, and as heavy a strain as they would stand was put on the lines, and blocks placed to assist in raising the toggle joint. As the tem-

perature approached its maximum for the day it was found that Pier. I and III were being pushed apart, the movement of Pier I being ¼ in. and of Pier III 1¼ ins.; the possibility of this motion had been considered, both in its effects on the masonry of the piers and in swinging the span. Masonry, like all the other construction, is elastic; the piers could move much more than these amounts without injury. The motion of the piers, however, worked against the shortening of the top chord by compression, and this attempt to swing the span failed. It almost succeeded, however, as was shown by the fact that some of the upper chord web bearings could be moved on the pins.

During the next two days four rods, each 1¾ ins. round, were placed in each truss, to connect the toggle joints with the center of the upper chord and aid in lifting the toggles; steam pipes were laid in the upper chords of the central span extending half way from Pier II to Pier III. Clamps (shown on Plate XIX) were placed at the adjustment points in each of the upper chords at the west end of the intermediate span; each clamp consisted of four rods, 2½ ins. diameter, with upset ends and nuts, bearing against pieces of rail and through oak blocks bearing against the edges of the tie plates of the chord sections.

On the morning of April 22d the operation of lifting the toggle joints began; there were 24 toggle rods, and the work of turning up the nuts required several hours of steady work; the joint was finally raised 3.75 ft. above the line of the lower chord. At 4 P.M. the steam pipes were connected to the locomotives and a heavy strain put on the clamps; in an hour the adjustment pins at the west end of the upper chords became loose and were taken out; the adjustment wedges in the upper chord at the east end of the span were loosened; the upper chord being now released at both ends, all difficulties were over and the span was practically swung. Night had come, and work was suspended until morning, when the hydraulic jacks in the lower chord at the east end of the span were slackened off and taken out, the wedges were removed, the castings in both chords at the west end of the span taken out and the pins put back in place. The toggle rods and lines were then slacked off, allowing the lower chord to assume its normal position, and the permanent sections of bottom chord were inserted.

During the erection and swinging of the intermediate span the

adjoining cantilever arms had been subjected to strains exceeding those due to the loading assumed in proportioning the members, but not exceeding safe limits. Twelve days were spent in swinging this span.

The erection of the channel span completed the continuous superstructure of the Memphis bridge. The floor system was put in, the riveting was continued, and the entire structure was ready for the passage of trains on the 12th of May, when the bridge was formally opened.

Deck Span.—The deck span at the west end of the bridge does not properly belong to this paper. It is a single triangular truss consisting of six panels, the floor being sustained at the half panel points by vertical posts. The only peculiarity about this truss is the fact that at the east end the support is taken in niches at the west side of Pier IV, the posts being shortened to fit these niches and the bottom chord brought upward to a connection with the post. The floor is kept uniform throughout, the east pair of stringers connecting with the floor beam over the center of Pier IV. At the west end the full depth of the truss is maintained, and an expansion bearing on rollers similar to those on Pier II is used.

Weights.—The following table gives the weight of the superstructure classified by spans. In this table the vertical posts over Piers I, II and III, and the supports on the piers, are divided between adjacent spans :

	Pounds.
East Approach	66 812
Anchorage Span	1 606 727
Cantilever Pier I	1 252 365
East Intermediate Span	2 329 759
Cantilever Pier II	1 284 674
Central Span	5 122 252
Cantilever Pier III	1 260 452
West Intermediate Span	2 327 845
Deck Span	1 072 951
	16 323 837

These are the actual shop weights, and the sum is the total amount of metal in the bridge.

The following table gives the weights as divided in estimating the strains. The portions directly over the piers, which are carried by the piers instead of by any portion of the trusses, are eliminated from the weights of the spans :

	Pounds.
Approach from Abutment to Anchorage Pier, including fence	66 812
Anchor rods and plates in Anchorage Pier	74 995
Anchorage bars, blocks, etc., below lower chord	57 936
Tetrapod and castings	6 777
Anchorage Span, exclusive of posts Lo Uo and castings on Pier I	1 305 084
Posts Lo Uo, portal between same and castings on Pier I	323 869
East Cantilever Arm	1 090 431
East Intermediate Span	2 329 759
Cantilever Arm, Pier II	1 090 430
Posts Lo Uo, portal for same, rollers, etc., and castings on Pier II	388 489
Central Span, exclusive of end posts, castings, etc.	4 757 987
Posts Lo Uo, portal for same, castings, etc., on Pier III	340 041
Cantilever Arm, Pier III	1 090 431
West Intermediate Span, exclusive of castings	2 269 340
Castings on top of Pier IV	58 505
Deck span castings in niches of Pier IV	11 262
Deck Span, exclusive of end supports and posts Lo Uo W	1 019 664
Castings Pier V and posts Lo Uo W	42 025
Total	16 323 837

The weights per foot referred to in this paper are calculations on the basis of this table.

These several tables give the weight of the steel in the structure. The weight of the wooden floor is additional, and was estimated at 630 lbs. per linear foot, this including rails and connections.

APPENDIX A.

KANSAS CITY AND MEMPHIS RAILWAY AND BRIDGE COMPANY.

Specifications for Superstructure of Bridge across the Mississippi River, at Memphis, Tennessee.

I.—GENERAL DESCRIPTION.

1. The superstructure is divided into two parts: First, the continuous superstructure of the main bridge; second, the deck span at the west end.

2. The continuous superstructure will consist of a central span (resting on Piers II and III), 621 ft. 0½ in. long, from each end of which will project a cantilever arm, 169 ft. 4½ ins. long; of an anchorage span (from the anchorage pier on the Tennessee shore to Pier I), 225 ft. 10 ins. long, from which will project a cantilever arm precisely like those projecting from the central span; of two intermediate spans 451 ft. 8 ins. long (one of which will be suspended from the cantilever arms projecting from Piers I and II, and the other will be suspended at the east end from the cantilever arm projecting from Pier III and will rest at the west end on Pier IV), the entire continuous superstructure being 2 258 ft. 4 ins. long, divided into one span of 225 ft. 10 ins., one of 790 ft. 5 ins., and two of 621 ft. 0½ in.

3. This continuous superstructure will be rigidly fastened to Piers I, III and IV, but will rest on expansion rollers on Pier II. Slip joints will be provided for expansion at the suspended ends of the independent spans.

4. The trusses will be placed 30 ft. between centers, and will be divided into panels 28 ft. 2¾ ins. long, the right being reserved to shorten the panels by an amount not exceeding ½ in. at any time before the work is actually manufactured.

5. The deck span at the west end will be 338 ft. 9 ins. long from the center of Pier IV to the center of the pin on Pier V, divided into 12 panels of 28 ft. 2¾ ins. each, the trusses being placed 22 ft. between centers. The east end of the span will be carried in niches on the west side of Pier IV; the west end will have roller bearings over the center of Pier V. This span will include a vertical bent which will carry the west end of the west pair of stringers.

6. The estimated approximate weight of the continuous superstructure is 13 000 000 pounds; that of the deck span, 1 000 000 lbs., making the total estimated weight of the superstructure of the bridge proper, 14 000 000 lbs.

PLANS.

7. Full detail plans showing all dimensions will be furnished by the engineer. The work shall be built in all respects according to these plans. The contractor, however, will be expected to verify the

correctness of the plans, and will be required to make any changes in the work which are necessitated by errors in these plans, without extra charge, where such errors could be discovered by an inspection of the plans.

II.—MATERIAL.

8. All parts, except nuts, swivels, clevises and wall pedestal plates, will be of steel. The nuts, swivels and clevises may be of wrought iron, but shall have sufficient strength to break the bodies of the members to which they are attached. The pedestal plates will be of cast iron.

9. All material shall be subject to inspection at all times during its manufacture, and the engineer and his inspectors shall be allowed free access to any works in which any portion of the material is made. Timely notice shall be given to the engineer, so that inspectors may be on hand.

Steel.

10. Steel will be divided into three classes: First, High-Grade Steel, which shall be used in all the principal truss members; second, Medium Steel, which shall be used in the floor system, laterals, portals, transverse bracing and the lacing of the truss members; third, Soft Steel, which shall be used only for rivets, and at the option of the contractor where wrought iron is permitted.

11. The bolsters which carry the large pin bearings on Piers I, II and III shall be of cast steel.

12. In any case where it seems doubtful what quality of steel is required, High-Grade Steel shall be used.

13. Steel may be made by the open-hearth or by the Bessemer process, but no steel shall be made at works which have not been in successful operation for at least one year.

14. All steel shall be made from uniform stock low in phosphorus, and the manufacturer shall furnish reports of the analysis of every melt, certified by a chemist satisfactory to the Chief Engineer.

15. In the finished product of open-hearth steel the amount of phosphorus shall not average more than $\frac{8}{100}$ of 1%, and never exceed $\frac{1}{100}$ of 1 per cent.

16. In the finished product of Bessemer steel, the amount of phosphorus shall not average more than $\frac{4}{100}$ of 1%, and never exceed $\frac{1}{200}$ of 1 per cent.

17. A sample bar ¾ in. in diameter shall be rolled from every melt, the method of obtaining the piece from which this bar is rolled to be the same in all cases, and the amount of work on this sample bar to be as nearly as practicable the same as on the finished product. The first laboratory test shall be made on this sample bar in its natural state without annealing.

18. A second sample bar having a cross-section of 1 sq. in. shall be cut from the finished product of every melt. The second laboratory test shall be made on this sample bar in its natural state without annealing.

19. In the laboratory tests all observations as to elastic limit, ultimate strength, elongation and reduction shall be made on a length of 8 inches.

20. A piece of each sample bar shall be bent 180° and closed up against itself without showing any crack or flaw on the outside of the bent portion.

21. The first laboratory test shall meet the following requirements:

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in.....	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in.....	71 500	65 500	57 000
Minimum Elastic Limit, lbs. per sq. in.....	42 000	38 000	32 000
Minimum percentage of Elongation in 8 ins.....	20	24	28
Minimum percentage of Reduction at Fracture.....	40	45	50

22. The second laboratory test shall meet the following requirements:

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in.....	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in.....	69 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in.....	40 000	37 000	30 000
Minimum percentage of Elongation in 8 ins.....	18	22	28
Minimum percentage of Reduction at Fracture.....	38	44	50

23. If the ultimate strength comes within 500 lbs. of the maximum or minimum limit, a second test will be made, and both tests will be required to come within the limits.

24. Every melt which does not conform with these requirements shall be rejected.

25. A full report of the laboratory tests shall be furnished, certified by an inspector accepted by the Chief Engineer.

26. The broken and bent specimens shall be preserved subject to the orders of the Chief Engineer.

27. Three notices of the acceptance of each melt shall be mailed on the day of such acceptance, stating the number of the accepted melt and quality of steel. Two of these notices shall be sent to the Chief Engineer at his Chicago and New York offices respectively; and one to the shop inspector at the works.

28. Analyses shall be made by the manufacturer of every melt, showing amount of phosphorus, carbon, silicon and manganese, and certified copies of these analyses shall be furnished to the mill inspector, who will forward them to the Chief Engineer.

29. Weekly reports in full detail, including reports of chemical analyses, shall be sent to the Chief Engineer at his Chicago office not later than the end of the week succeeding the week in which such tests are made.

30. Three notices of the shipment of manufactured material identifying the melts and dimensions shall be mailed on the day after such shipments are made, in the same manner as the notices of acceptance of material.

31. Every finished piece of steel shall be stamped on one side near the middle of the bar and also on both ends of the bar with a number, identifying the melt.

32. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds.

33. The cross-sections shall never differ more than 2% from the ordered cross-sections as shown by the dimensions on the plans.

34. All sheared edges shall be planed off so that no rough or sheared surface shall ever be left on the metal.

35. Steel for pins shall be sound and entirely free from piping. All pins in the main trusses shall be drilled through the axis.

CAST STEEL.

36. A sample bar 1¼ ins. in diameter and 16 ins. long shall be cast from every melt. This sample bar shall then be turned down to ¾ in. in diameter and the laboratory tests made upon it.

37. These laboratory tests shall show an ultimate strength of at least 70 000 lbs., an elastic limit of at least 40 000 lbs. and an elongation of at least 15% in 8 ins. and a reduction of 18% at point of fracture.

38. Steel castings shall be sound and as free as possible from blow holes.

39. If on the finished surface the blow holes cover more than $\frac{1}{100}$ part of the entire surface, and if any blow hole exceeds ⅛ in. in diameter, the casting shall be rejected.

CAST IRON.

40. Cast iron shall be the best quality of dark gray charcoal iron of a quality suitable for car wheels, the castings to be entirely sound and free from blow holes.

III.—MANUFACTURE.

41. The work shall be done in all respects according to the detail plans furnished by the Chief Engineer.

42. Where there is room for doubt as to the quality of work required by the plans or specifications, the doubt shall be decided by using the best class of work which any interpretation would admit of.

43. All workmanship, whether particularly specified or not, must be of the best kind now in use. Past work done for the same chief engineer will never be recognized as a precedent for the use of other than the best kind of work.

44. Ragged edges or any kind of irregularities or unnecessary roughness will be sufficient ground for rejection.

45. All surfaces in contact shall be cleaned and painted before they are put together.

46. All work shall be finished in the shop and ample time given for inspection.

47. No material shall be loaded on cars until accepted by the inspector.

48. The finishing of work after loading will not be permitted.

SOLID DRILLED WORK.

49. All riveted members which are made of High-Grade Steel and all other pieces connecting with such members shall be solid drilled, no punching whatever being allowed, excepting lacing bars which may be punched and reamed.

50. All plates, angles and shapes shall be carefully straightened at

the shops before they are put together. Mill straightening will not be considered to meet this requirement.

51. The pieces shall be then assembled and held in position by clamps and bolts.

52. Where bolts passing through the metal are used, the holes shall be drilled in all metal more than $\frac{3}{4}$ in. thick, the diameter of the drilled hole to be at least $\frac{1}{8}$ in. less than the diameter of the finished hole.

53. In metal not more than $\frac{3}{4}$ in. thick, punched holes may be used for fitting up, the diameter of the punched hole not to be more than three-quarters the diameter of the finished hole, and the number of punched holes never to exceed eight in any one plate or four in one flange of any one angle.

54. After assembling, the work shall be drilled, the rivet holes being carefully spaced in truly straight lines and at the exact distances shown on the plans.

55. After the drilling is completed, a special reamer shall be run over both edges of every hole, so as to remove the sharp edges and make a fillet of at least $\frac{1}{16}$ in. under each rivet head.

56. The assembled parts shall then be riveted up without taking apart, unless specially directed by the Chief Engineer.

57. In general, all holes which are to pass through several thicknesses of metal shall be drilled with all those pieces of metal assembled in the exact relative position they are to hold in the bridge.

58. In the case of connections between members having four webs, one member may be finished complete with the splice plates riveted on. The two inside webs of the adjoining member, one end being already faced, may then be fitted up separately in their true position and the rivet holes in the splices drilled. These inside webs may then be removed; the member to which they belong shall be assembled, riveted up complete and the ends faced, the facing to agree exactly with the two ends already faced (see Section 67). The member shall then be fitted to the adjoining member, and the rivet holes in the splices connecting the outside web shall be drilled.

59. The size of rivets shown on the plans is the size of the cold rivet before heating.

60. The diameter of the finished hole shall not be more than $\frac{1}{16}$ in. greater than the diameter of the cold rivet. It is intended that the heated rivet shall not drop into the hole, but require a blow from a hammer to force it in. If it is found that rivets will drop easily into the holes the inspector will condemn those rivets and order a larger size.

61. In all cases where riveting is to be done in the field, the parts so to be riveted shall be fitted together in the shops and the rivet holes drilled while they are so assembled.

62. The riveted connections of the portals, cross frames and floor beams with the posts and chords shall be drilled with the several parts fitted together, excepting in the case of interchangeable floor beams.

63. An iron templet not less than 2 ins. thick may be used instead of the floor beams when drilling the holes in the chords, and the same templet instead of the chords when drilling the holes in the floor beams; a templet may be used in the same manner in drilling the connections between the floor beam and the supported upright at panel points where two inclined members come together; but the connection between the floor beam and the vertical suspenders at panels point L_1 and L_2 of the intermediate spans shall be drilled with the parts actually assembled, and marked. With this arrangement two floor

beams at each end of the intermediate spans, making eight in all, become special; the other floor beams are classed as interchangeable.

64. All rivets shall be driven by power wherever this is possible.

65. All rivets shall be regular in shape, with hemispherical heads concentric with the axis and absolutely tight. Tightening by calking or recupping will not be allowed. This applies to both power-driven and hand-driven rivets.

66. All pin holes and holes for turned bolts passing through the whole width of a riveted member shall be bored or drilled after all other work is completed.

67. All surfaces in contact shall be carefully faced, the facing to be done after the entire member is assembled and riveted up except that in the case of chord sections with four webs the inside webs may have one end faced before they are assembled, these two faced ends to be carefully held against a plane surface when assembled and the corresponding ends of the other two webs to be faced after riveting and to agree with the ends already faced.

68. When two chord pieces are fitted together complete in the shop there shall be no perceptible wind in the length of the two sections. The chords are generally made in two panel lengths, or 56 ft. 5½ ins. long. In the case of shorter lengths a sufficient number of pieces shall be put together to make a continuous length equal to two of the long sections.

69. All chord sections shall be stamped at each end on the outside with letters and numbers designating the joints in accordance with the diagram plan furnished by the Chief Engineer.

70. The posts shall be fitted together for their entire length and bolted up and when so fitted shall be perfectly straight and free from wind.

71. The same rule shall apply to the marking of the posts as to the marking of the chords.

72. Pin holes shall be bored truly and at exact distances parallel with one another and at exactly right angles to the axis of the member.

73. Pin holes in the posts shall be truly parallel with one another and shall be at right angles to the axis of the post.

74. Pin holes shall be bored with a sharp tool which will make a clean, smooth cut. Two cuts shall always be taken, the finishing cut never to be more than $\frac{1}{8}$ in. Roughness in pin holes will be sufficient reason for rejecting a whole member.

75. Measurements shall be made from an iron standard of the same temperature as the member measured.

PUNCHED AND REAMED WORK.

76. All riveted members which are composed entirely of Medium Steel may be punched and reamed, but this does not apply to the connections between such members and High-Grade Steel members, which connections shall be solid drilled throughout.

77. All plates, angles and shapes shall be carefully straightened at the shops before they are laid out. Mill straightening will not be held to meet this requirement.

78. The rivet holes shall be marked from templets and these templets shall lie flat without distortion when the marking is made.

79. The angles of stringers must be square and straight. The web plate must not project above the angles and the top surfaces of the

top angles must be such that the outside edges are never above a true plane and never more than $\frac{1}{16}$ in. below a true plane coincident with the roots of the angles.

80. The outside angle at the root of the angles connecting the stringers with the floor beams or the floor beams with the posts, chords or other members, shall never be less than a right angle, and the excess over a right angle shall never be greater than $\frac{1}{8}$ in. in the longer leg of the angle; the angle shall be perfectly straight.

81. In fitting these angles to stringers or floor beams they shall be so fitted that the exact length is measured to the root of the angle, the two roots being in exactly the same plane; the entire end of the assembled member shall then be faced. The effect of these requirements will be to prevent any reduction of area of the angle at the root by facing and to secure a true surface of the whole width of the connection which will require no strain in the rivets to draw the parts together.

82. After laying out with templets, the rivet holes may be punched with a punch at least $\frac{3}{32}$ in. smaller than the diameter of the rivets as given on the plans, and working in a die only $\frac{1}{64}$ in. larger than the punch.

83. The several parts of the member shall then be assembled and the holes reamed so that at least $\frac{1}{16}$ in. of metal is everywhere taken out.

84. After the reaming is completed, a special reamer shall be run over both edges of every hole so as to remove the sharp edges and make a fillet of at least $\frac{1}{16}$ in. under each rivet head.

85. The pieces shall be riveted together without taking apart.

86. All requirements as to size and quality of rivets and manner of riveting and measuring shall be the same as the requirements for solid drilled riveted work.

87. All bearing surfaces shall be truly faced.

88. All sheared edges shall be planed off and all punched holes shall be drilled out so that none of the rough surface is ever left upon the work.

FORGED WORK.

89. The heads of eye-bars shall be formed by upsetting and forging into shape by a process acceptable to the Chief Engineer. No welds will be allowed.

90. After the working is completed, the bars shall be annealed in a suitable annealing furnace by heating them to an uniform dark red heat and allowing them to cool slowly.

91. The form of the heads of the steel eye-bars may be modified by the contractors to suit the process in use at their works, but the thickness of the head shall not be more than $\frac{1}{16}$ in. greater than that of the body of the bar, and the heads shall be of sufficient strength to break the body of the bar.

92. The heads and the enlarged ends for screws in laterals, suspenders and counters shall be formed by upsetting and shall be of sufficient strength to break the body of the bar.

93. Nuts, swivels and clevises, if made of steel, shall be forged without welds; whether made of steel or wrought iron, one of each size shall be tested and be of sufficient strength to break the bars to which they are attached.

94. Eye-bars shall be bored truly and at exact distances, the pin

holes to be exactly on the axis of the bar, and at exactly right angles to the plane of the flat surfaces.

95. When six bars of the same billed length are piled together, the two pins shall pass through both pin holes at the same time without driving. Every bar shall be tested for this requirement.

96. Pin holes shall be bored with a sharp tool that will make a clean, smooth cut. Two cuts shall always be taken, the finishing cut never to be more than $\frac{1}{32}$ in. Roughness in pin holes will be sufficient reason for rejecting bars.

97. Twenty full-sized steel eye-bars shall be selected from time to time from the bars made for the bridge by the inspector for testing.

98. No bars known to be defective in any way shall be taken for test bars, but the bars shall be selected as fair average specimens of the good bars which would be accepted for the work.

MACHINE-WORK.

99. All bearing surfaces shall be faced truly.

100. Chord sections and half-post sections shall be faced after they are riveted up complete, the facing to be perfectly true and square. In the case of four web chords, one end of the two inside webs only may be faced before riveting up.

101. The ends of the stringers and of floor beams shall be squared in a facer.

102. All surfaces, so designated on the plans, shall be planed.

103. All sheared edges shall be planed off, and all punched holes shall be drilled or reamed out.

104. All pins shall be accurately turned to a gauge, and shall be of full size throughout.

105. Pin holes shall be bored to fit the pins with a play not exceeding $\frac{1}{32}$ in. These requirements apply to lateral connections as well as to any other pins.

106. The plans show the distances between centers of pin holes. Shop measurements, however, shall be made between the bearing edges of the pin holes, that is, between the inside edges of compression members and the outside edges of tension members, with a proper allowance for the diameter of the pin. An iron standard of the same temperature as the piece measured shall always be used.

107. All screws shall have a truncated V thread, United States standard sizes.

108. Special pains shall be taken with the roller bearings on Pier II. The castings shall be accurately fitted together, and when bolted up the top surface shall be a perfectly true plane.

109. The rail plates shall be planed on the bottom after being riveted up, then planed on the top, and the surface polished. Any roughness or irregularity which prevents an uniform opening between the rail heads shall be planed out.

110. The rollers shall have the hollow sides planed, and the bearing surfaces turned to a perfectly true cylinder and polished.

111. The rods passing through the rollers shall fit the holes with a play not exceeding $\frac{1}{32}$ in.

112. The side bars connecting the rods shall be drilled to fit the rods with a play not exceeding $\frac{1}{32}$ in., and the upper and lower surfaces of these side bars shall be planed.

113. The lower side bar in each instance shall be fitted with a graduated bronze scale, so divided as to register inches of motion of the top

bearing, and the upper bar shall be fitted with a German-silver vernier, so divided as to read to sixteenths of inches as graduated on the scale.

114. The two bearings, including everything between the masonry and the 14-in. pin, shall be set up complete in a level position at the Athens shops, and shall not be shipped before they have been examined and approved by the Chief Engineer. They shall be ready for his inspection on or before January 1st, 1891.

115. Special pains shall be taken with the slip joints at the suspended ends of the intermediate spans; the surface of the joints shall be polished and fitted exactly.

MISCELLANEOUS.

116. All material shall be cleaned, and, if necessary, scraped and given one heavy coat of Cleveland iron-clad paint, purple brand, put on with boiled linseed oil, before shipment. This applies to everything except machine-finished surfaces.

117. The same paint shall be used wherever painting is required.

118. All machine surfaces shall be cleaned, oiled, and given a heavy coat of white lead and tallow before shipment. The inspector must see that this is a substantial coat, such as is used on machinery, and not a merely nominal covering.

119. All small bolts, all pins less than 6 in. in diameter, the expansion rollers, and everything with special work on it, shall be carefully boxed before shipment.

120. The contractor will be required to furnish the field rivets for erection, furnishing 20% in excess of each size over and above the number actually required, but this excess will not be estimated, but considered as taking the place of the work which is not done on these rivets.

V.—INSPECTION.

121. The mill inspection shall be performed at the expense of the contractor by an inspector accepted by the Chief Engineer.

122. This inspector will be required to furnish the certificates and notices in the manner specified above.

123. The mill inspector shall from time to time check the manufacturers' analyses by analyses made by an independent chemist.

124. The acceptance of material by such inspector will not be considered final, but the right is reserved to reject material which may prove defective or objectionable at any time before the completion of the contract.

125. The inspection at the shops will be under the charge of an inspector appointed by the Chief Engineer, with such assistants as may be required.

126. Such inspector will be considered at all times the representative of the Chief Engineer, and his instructions shall be followed in the same manner as if given by the Chief Engineer.

TESTS OF FULL-SIZED BARS.

127. The test of full-sized eye-bars shall be made in the large testing machine at Athens.

128. These bars will be required to develop an average stretch of 12%, and a minimum stretch of 10%, before breaking. The elongation shall be measured on a length of not less than 20 ft., including the fracture.

129. The bar will be required to break in the body.

130. They shall also show an elastic limit of not less than 32 000 lbs., and an ultimate strength of not less than 62 000 lbs., as indicated by the registering gauges of the testing machine at Athens.

131. In the case of bars too long for the machine, the bars shall be cut in two, each half reheaded, and both halves tested in the machine, the two tests, however, to count as a single test bar.

132. If the capacity of the machine (estimated at 1 200 000 lbs.) is reached before the bar is broken, the bar shall be taken out of the machine and the edges shall be planed off for a length of 10 ft. at the center until the section is reduced to the equivalent of 16 sq. ins. of section of the original bar. The bar shall then be placed in the machine and broken; when this is done, the elongation shall be measured on a length of 8 ft. and an ultimate strength of 60 000 lbs., computed on the 16 ins. of original section will be considered satisfactory.

133. In these tests, a failure to meet the required elongation will be considered fatal, and be a sufficient cause for condemning the bars represented by the bar so tested; but the Chief Engineer shall examine carefully into the cause of the breakage of any bar which does not meet the requirements, and may order additional tests if he sees fit.

134. The failure of a bar to break in the body shall not be considered sufficient reason for rejection, provided the required elongation is obtained and not more than one-quarter of the bars break in the head.

135. In all requirements and tests the quantities given are minimum or maximum requirements, and not averages unless expressly so stated.

V.—TERMS.

136. The work will be paid by the pound of finished work loaded on cars at Buffalo.

137. On riveted work and other material shipped from Athens, the difference between the freight rates from Athens to Memphis and from Buffalo to Memphis will be borne by the contractor.

138. No material will be paid for which does not form a part of the finished superstructure.

139. All expenses of testing shall be borne by the contractor.

140. All riveted work shall be manufactured at the Athens shop, unless by special permission of the Chief Engineer.

141. Prices will be per pound at separate rates for High-Grade Steel and for Medium Steel.

142. To avoid complications, all members, the principal parts of which are High-Grade Steel, shall be estimated as wholly of High Grade Steel, and all members, the principal parts of which are of Medium Steel, shall be estimated as wholly of Medium Steel.

143. Cast Steel shall be estimated as High-Grade Steel.

144. Cast and wrought iron shall be estimated at the same price as Medium Steel.

145. The anchorage span, the east cantilever arm and one-half the east intermediate span shall be completed and shipped on or before October 1st, 1890.

146. The deck span shall be completed and shipped on or before December 1st, 1890.

147. The central span and the two adjoining cantilever arms shall be shipped complete on or before June 1st, 1891.

148. The west intermediate span and the second half of the east in-

termediate span shall be shipped complete on or before August 1st, 1891.

149. Approximate estimates shall be made at the end of each month of the material received and work performed up to that time.

150. In these estimates material received at the shops, but not manufactured, shall be estimated at 65% of the contract price for finished material.

151. Material manufactured, but not shipped, shall be estimated at 85% of the contract price.

152. Material completed and shipped shall be estimated at the full contract price.

153. Payments shall be made on these estimates on or about the middle of the following month, deducting therefrom 10%, which shall be held as security until the completion of the entire contract.

154. In these monthly estimates no material will be estimated as received at the shop more than six months before the date set for the completion and shipment of such material.

155. In these monthly estimates no material will be estimated as manufactured more than four months before the date set for the completion and shipment of such material.

156. The contractors will be required to keep the material at their shops insured from injury by fire to the full amount of the payments made on such material by the Bridge Company.

VI.—ERECTION.

157. The contractor will be expected to receive all material as it arrives on the cars, to unload this material and store it in a material yard until ready for erection.

158. He will be held responsible for the custody and care of all superstructure material after its arrival.

159. The material of the main continuous superstructure will be delivered on cars on the east side of the river.

160. When ready for erection, the Bridge Company will switch any cars on which this material has been loaded, to a point where it can be transferred to barges, no charge being made for such switching.

161. All material for the deck span at the west end will be delivered on cars on the west side of the river.

162. A track will be laid to a convenient position for unloading material near Pier V, and no switching will be done after the material has once been unloaded.

163. The contractor will be required to keep all the material in good condition, and in case of its becoming dirty or rusty will be expected to clean it before erecting.

164. The contractor will be required to paint all surfaces which will be inaccessible for painting after erection, the paint being furnished by the Bridge Company.

165. The contractor will be required to furnish all tools, barges and false-work of every description, excepting power riveters.

166. The contractor will be required to remove all work which he may put in the river so that there will be nothing left either to interfere with navigation or to catch drift.

167. No holes shall be drilled or bolts placed in the piers without the express permission of the Engineer.

168. All bolts so put in shall be removed and the holes carefully

filled with Portland cement mortar, and any damages done shall be charged to the contractor.

169. The contractor will be required to erect the superstructure complete in every respect, including riveting.

170. Everything is to be completed ready to receive the timber floor.

171. The erection shall include the placing and riveting of the iron hand rail.

172. The contractor will be expected to raise the ties for the central span and the adjoining cantilever arms, and distribute them without charge. This does not include any framing, fitting or bolting. The ties will be delivered to the contractor loaded on barges.

173. The central span will be raised on false-work.

174. The west intermediate span will be raised on false-work.

175. The east intermediate span may be raised on false-work, or without, at the option of the contractor.

176. The anchorage arm east of Pier I will be raised on false-work.

177. The three projecting cantilever arms will be built out without false-work.

178. It is expected that the anchorage arm and the cantilever arm projecting from Pier I can be raised in the fall of 1890. That the deck span at the west end can be raised in the following winter. That the false work for the central span can be put in in August and September of 1891, and the erection of this span completed in the following month. That the cantilevers can be built out and the entire bridge completed by January 1st, 1892.

179. All erection shall be done under the direction of the Chief Engineer and in conformity with his requirements.

180. The wall plate castings shall be set on Piers II and III before the bottom chord is placed.

181. The expansion rollers and the bolster complete shall be set on Pier III. The bottom chords shall then be put together and riveted up complete. The expansion end shall then be adjusted so that the axis of the rollers will be exactly vertical at a temperature of 70° Fahr. This adjustment shall be made at a time when there has been no sun on the steelwork for 10 continuous hours, and when there has been no sudden change of temperature. The span shall be erected complete and the end rollers shall be examined again, and if any error is found, it shall be corrected, the correction being made under the same conditions as to sunshine and sudden changes of temperature as the original adjustment. Special care shall be taken with the rollers while the span is being swung, and if by any accident they get out of place, the span shall be wedged again, and the rollers be readjusted.

182. The eye-bars in the end panel of the top chord shall be stiffened so as to resist compression by fitting planks between the bars and bolting the whole together.

183. When the erection of the central span is completed, the two cantilever arms shall be built out, and the two intermediate spans erected, thus completing the bridge.

184. All rivets shall be regular in shape with hemispherical heads concentric with the axis and absolutely tight. Tightening by calking or recupping will not be allowed.

185. All riveted joints which have to resist tension, this including all joints in both chords of the central span and all joints in the bottom chord of the intermediate spans shall be riveted by power, except in such special cases as the engineer may authorize hand-driven rivets. This authority will never be given for rivets in splices of web-plates.

186. A power riveter, with air pump or with hydraulic pump and accumulator will be furnished by the Bridge Company. The contractor will be required to keep the same in repair and will not be relieved from any responsibility in this connection, the Bridge Company only agreeing to bear the cost of the machine.

187. No extra bills are to be rendered by the contractor, except for new work not embraced in the contract. Charges for reaming holes, fitting bolts in place of rivets and other small work of this class will not be allowed.

188. The setting of the wall plate castings, including the drilling of holes in masonry for the anchor bolts, the packing of rust cement or lead under the castings, and all other work connected therewith, is to be done by the contractor.

189. The contractor will be responsible for any damages which the Bridge Company may be held liable for in consequence of any of his work.

GEORGE S. MORISON,
Chief Engineer.

JANUARY 4TH, 1890.

APPENDIX B.

MODIFICATIONS OF SPECIFICATIONS FOR SUPERSTRUCTURE OF BRIDGE ACROSS THE MISSISSIPPI RIVER, AT MEMPHIS, TENN., ACCEPTED APRIL 22D, 1890.

STEEL.

10. Steel will be divided into three classes: first, High-Grade Steel, which shall be used in all the principal truss members; second, Medium Steel, which shall be used in the floor system, laterals, portals, transverse bracing and the lacing of the truss members; third, Soft Steel, which shall be used only for rivets and at the option of the contractor where wrought iron is permitted.

11. The bolsters which carry the large pin bearings on Piers I, II and III shall be of Cast Steel.

12. In any case where it seems doubtful what quality of steel is required, High-Grade Steel shall be used.

13. Steel shall be made by the open-hearth process, but no steel shall be made at works which have not been in successful operation for at least one year.

14. All steel shall be made from uniform stock low in phosphorus, and the manufacturer shall furnish reports of the analysis of every melt, certified by a chemist satisfactory to the chief engineer.

15. In the finished product of acid open-hearth steel the amount of phosphorus shall not average more than $\frac{8}{100}$ of 1%, and never exceed $\frac{1}{10}$ of 1 per cent.

16. In the finished product of basic open-hearth steel, the amount of phosphorus shall not average more than $\frac{6}{100}$ of 1%, and never exceed $\frac{1}{100}$ of 1 per cent.

17. A sample bar $\frac{3}{4}$ in. in diameter shall be rolled from a 4-in. ingot cast from every melt. The first laboratory test shall be made on this sample bar in its natural state without annealing.

18. A second sample bar having a cross-section of 1 sq. in. shall be

cut from the finished product of every melt. The second laboratory test shall be made on this sample bar in its natural state without annealing.

19. In the laboratory tests all observations as to elastic limit, ultimate strength, elongation and reduction shall be made on a length of 8 inches.

20. A piece of each sample bar shall be bent 180°, and closed up against itself without showing any crack or flaw on the outside of the bent portion. Two successful tests out of a total of three will be accepted as satisfactory.

21. The first laboratory test shall meet the following requirements:

	High-Grade and Medium Steel.	Soft Steel.
Minimum Ultimate Strength, lbs. per sq. in	65 000	57 000
Minimum Elastic Limit, lbs. per sq. in	38 000	32 000
Minimum percentage of Elongation in 8 ins	20	28
Minimum percentage of Reduction at Fracture	40	50

22. The second laboratory test shall meet the following requirements:

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in	69 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in	40 000	37 000	30 000
Minimum percentage of Elongation in 8 ins	18	22	28
Minimum percentage of Reduction at Fracture	38	44	50

23. If the ultimate strength comes within 500 lbs. of the maximum or minimum limit, a second test will be made, and both tests will be required to come within the limits.

24. Every melt which does not conform with these requirements shall be rejected. Cases in which the tests are thought not to give fair representations of the character of the material shall be referred to the Chief Engineer.

25. A full report of the laboratory tests shall be furnished, certified by an inspector accepted by the Chief Engineer.

26. The broken and bent specimens shall be preserved subject to the orders of the Chief Engineer.

27. Three notices of the acceptance of each melt shall be mailed on the day of such acceptance, stating the number of the accepted melt and quality of steel. Two of these notices shall be sent to the Chief Engineer at his Chicago and New York offices respectively, and one to the shop inspector at the works.

28. Analyses shall be made by the manufacturer of every melt, showing amount of phosphorus, carbon, silicon and manganese and certified copies of these analyses shall be furnished to the mill inspector who will forward them to the Chief Engineer. The phosphorus and carbon

analyses shall always be made. Analyses for silicon and manganese shall be made whenever called for by the inspector. Copies of all analyses, whether made by request of the inspector or by the desire of the manufacturer, shall be furnished to the Chief Engineer.

29. Weekly reports in full detail, including reports of chemical analyses, shall be sent to the Chief Engineer at his Chicago office not later than the end of the week succeeding the week in which such tests are made.

30. Three notices of the shipment of manufactured material, identifying the melts and dimensions, shall be mailed on the day after such shipments are made, in the same manner as the notices of acceptance of material.

31. Every finished piece of steel shall be stamped on one side near the middle of the bar, and also on both ends of the bar, with a number identifying the melt. If it is found impossible to stamp any particular piece on the ends, the inspector may authorize the two end stamps to be put on the surface within $\frac{1}{2}$ in. of each end, the fact of the stamping being done in this way to be specified distinctly on all notices and invoices; this may be done, however, by an agreed character.

32. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds.

33. The cross-sections shall never differ more than 2% from the ordered cross-sections as shown by the dimensions on the plans.

34. All sheared edges shall be planed off so that no rough or sheared surface shall ever be left on the metal.

35. Steel for pins shall be sound and entirely free from piping. All pins in the main trusses shall be annealed before they are turned and shall be drilled through the axes.

GEORGE S. MORISON,
Chief Engineer.

MAY 6TH, 1890.

APPENDIX C.

MODIFICATIONS OF SPECIFICATIONS FOR SUPERSTRUCTURE OF BRIDGE ACROSS THE MISSISSIPPI RIVER AT MEMPHIS, TENN., ACCEPTED DECEMBER 29TH, 1890.

STEEL.

10. Steel will be divided into four classes: first, High-Grade Steel, which shall be used in all the principal truss members except eye-bars; second, Eye-Bar Steel, which shall be used only in eye-bars; third, Medium Steel, which shall be used in the floor system, laterals, portals, transverse bracing and lacing of the truss members; fourth, Soft Steel, which shall be used only for rivets, and at the option of the contractor where wrought iron is permitted.

11. The bolsters which carry the large pin bearings on Piers I, II and III shall be of cast steel.

12. In any case where it seems doubtful what quality of steel is required, High-Grade Steel shall be used.

13. Steel shall be made by the open-hearth process, but no steel shall be made at works which have not been in successful operation for at least one year.

14. All steel shall be made from uniform stock low in phosphorus,

and the manufacturer shall furnish reports of the analysis of every melt, certified by a chemist satisfactory to the Chief Engineer.

15. In the finished product of acid open-hearth steel the amount of phosphorus shall not average more than $\frac{8}{100}$ of 1%, and never exceed $\frac{1}{10}$ of 1 per cent.

16. In the finished product of basic open-hearth steel the amount of phosphorus shall not average more than $\frac{4}{100}$ of 1%, and never exceed $\frac{7}{100}$ of 1 per cent.

17. A sample bar $\frac{3}{4}$ in. in diameter shall be rolled from a 4-in. ingot cast from every melt. A laboratory test shall be made on this sample bar in its natural state without annealing, but this test may be made subsequent to the acceptance of the material, and shall be for record only.

18. A second sample bar having a cross-section of 1 sq. in. shall be cut from the finished product of every melt. The second laboratory test shall be made on this sample bar in its natural state without annealing.

19. In the laboratory tests all observations as to elastic limit, ultimate strength, elongation and reduction shall be made on a length of 8 inches.

20. A piece of each sample bar shall be bent 180°, and closed up against itself without showing any crack or flaw on the outside of the bent portion. Two successful tests out of a total of three will be accepted as satisfactory.

21. The first laboratory test shall meet the following requirements:

	High-Grade, Eye-Bar and Medium Steel.	Soft Steel.
Minimum Ultimate Strength, lbs. per sq. in.	65 000	57 000
Minimum Elastic Limit, lbs. per sq. in.	38 000	32 000
Minimum percentage of Elongation in 8 ins.	20	28
Minimum percentage of Reduction at Fracture	40	50

22. The second laboratory test shall meet the following requirements:

	High-Grade Steel.	Eye-Bar Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in.	78 500	75 000	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in.	69 000	66 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in.	40 000	38 000	37 000	30 000
Minimum percentage of Elongation in 8 ins.	18	20	22	28
Minimum percentage of Reduction at Fracture.	38	40	44	50

23. If the ultimate strength comes within 500 lbs. of the maximum or minimum limit, a second test will be made, and both tests will be required to come within the limits.

24. Every melt which does not conform with these requirements shall be rejected. Cases in which the tests are thought not to give fair representations of the character of the material shall be referred to the Chief Engineer.

Remarks.	Span.	Nominal.		
		Width.	Thickness.	Length, C
Flaw in back of eye	Experimental	10	1 1/8	160.63
High steel	"	10	1 1/8	158.07
	"	10	1 1/8	358.93
	"	10	1 1/8	361.23
	Anchorage	10	1 1/16	162.38
	"	6	1 1/16	291.26
Bar cut in two. Reheaded, not reannealed. First half: bar stretched to full capacity of machine, then planed to a section equivalent to 16 sq. ins. original	"	6	1 1/16	314.18
	"	10	1 1/16	287.37
	"	10	1 1/16	284.28
	"	10	1	287.88
	"	10	2 3/16	222.88
Second half treated same as above	"	10	2 1/16	222.48
Piping in fracture	"	10	1 7/8	464 03
Retest of above. Reheaded, not reannealed. Broke in new head. Elongation is total for both tests	"	10	1 7/8	198.03
Soft steel suspender	"	7	1 3/16	314.04
Foreign substance in fracture	Central	10	2 3/16	338.73
Retest of above. Reheaded, not reannealed. Planed to equivalent of 16 sq. ins. original area	"	10	2 3/16	.....
First half of bar cut in two. Reheaded, not reannealed	"	10	1 13/16	251.58
Second half of above	"	10	1 13/16	250.08
Above reheaded, not reannealed	"	10	1 13/16	194.88
First half	"	10	1 7/8	250.28
Second half of above. One head buckled, rebored, and then test finished	"	10	1 7/8	247.78
Soft steel suspender	"	7	1 5/16	385.73
First half	Cantilever	7	1 1/2	385.78
Second half. Spot of foreign matter in fracture	"	10	1 7/8	249.98
	"	10	1 7/8	250.23
	"	10	2 3/16	341.28
Bar strained to 5 930 lbs. per square inch, then planed to equivalent of 16 sq. ins., original section. Area reduced 1' from fracture, 12 per cent	"	10	1 3/16	249.48
	"	10	1 3/16	249.58
	"	10	1 13/16	284.82
Second part of above	"	10	1 13/16	221.98
First part	"	10	1 13/16	221.98
Second part	"	10	1 13/16	172.43
Retest of above. Reheaded, not reannealed	"	10	1	361.68
High steel bar cut in two. Reheaded, not reannealed. Test completed as below	East intermediate	7	1 1/4	258.68
First half above. Broke in unannealed end near heat line of new head	"	8	1 3/4	478.88
Second half broke like above. Area between fracture and new head reduced 24.1 per cent	"	8	1 3/4	236.28
	"	8	1 3/4	240.28
Bar cut in two. Reheaded, not reannealed. Retested as below	"	8	1 1/4	478.88
First part of above	"	8	1 1/4	236.98
	"	8	1 1/4	238.18
Second part of above. Broke in unannealed part of bar on heat line of new head	"	8	1 3/4	254.68
	"	8	2 3/16	338.58
Soft steel suspenders	West intermediate	7	1 1/16	258.68
" " Full capacity of machine reached	"	9	2 3/16	338.58
" " First part	"	9	1 1/16	206.58
" " Second part	"	9	1 1/4	205.38
Lower lateral. Broke at back end of upset for screw, disclosing piece of iron welded in	"	6	1 3/16	409.08
Lower lateral	"	6	1 3/16	416.78
" "	"	4	1 1/16	422.18
" "	"	4	1	421.88
" "	"	4	1 1/2	423.08
First part	Deck span	8	1 13/16	279.98
Second "	"	8	1 13/16	279.88
First "	"	7	1	289.28
Second "	"	7	1	249.48

TESTS ON FULL-SIZED EYE-BARS.

Dimensions, Inches.									
Original.					After Test.		Reduction of area.	Elongation.	
minal.	Actual.								
Thickness.	Length, C to C.	Gauged length.	Width.	Thickness.	Width.	Thickness.	Percent.	Inches.	Percen
1 1/2	160.63	120	10.07	1.50	8.00	1.14	39.6	20.2	16.8
1 1/2	158.07	120	10.16	1.46	....	....	....	10.75	8.96
1 3/8	358.93	324	9.95	1.73	7.86	1.32	39.7	26.6	8.2
1 3/8	361.23	312	9.98	1.75	7.77	1.25	44.4	36.8	11.8
1 1/2	162.38	120	10.05	1.50	8.06	1.15	38.5	38.5	17.3
1 1/2	291.26	252	6.08	1.13	4.62	0.64	56.9	33.7	13.4
1 1/2	314.18	288	6.09	1.12	4.83	0.82	41.9	39.6	13.8
1 11/16	287.37	240	10.07	1.67	8.07	1.25	40.0	32.5	13.5
1 15/16	284.28	240	9.92	1.95	7.97	1.47	39.4	36.8	15.3
1	287.88	240	9.94	0.99	8.05	0.80	34.6	32.9	13.7
2 3/16	222.88	96	10.05	2.20	6.09	1.77	32.6	13.0	13.5
2 1/16	222.48	96	10.05	2.18	5.75	1.63	41.4	14.6	15.2
1 1/2	464 03	420	10.12	1.86	9.99	1.80	4.5	10.4	2.5
1 7/8	198.03	144	....	....	....	....	....	4.7	3.2
1 3/16	314.04	276	7.12	1.17	5.14	0.77	52.5	59.3	21.5
2 1/16	338.73	300	10.07	2.20	9.73	2.11	7.3	20.8	6.9
2 3/16	.....	96	....	....	5.88	1.70	37.5	18.4	19.2
1 13/16	251.58	204	10.03	1.81	8.08	1.39	38.1	28.9	14.1
1 13/16	250.08	204	10 05	1.81	....	....	....	5.7	2.8
1 13/16	194.88	144	....	....	....	....	....	5.2	3.6
1 3/8	250.28	204	9.97	1.37	8.39	1.11	31.8	24.0	11.8
1 3/8	247.78	204	9.99	1.37	8.15	1.07	36.3	23.0	11.3
1 5/16	385.73	348	7.02	1.31	5.16	0.92	48.4	78.3	22.5
1 1/4	385.78	348	7.01	1.26	5.13	0.83	51.8	47.3	13.6
1 1/2	249.98	204	9.99	1.62	7.49	1.11	48.6	39.4	19.3
1 1/2	250.23	204	10.02	1.63	9.49	1.53	11.1	19.6	9.6
2 1/16	341.28	96	9.96	2.05	7.52	1.91	10.3	11.8	12.3
1 5/16	249.48	204	10.13	1.30	7.92	0.92	44.6	32.0	15.7
1 5/16	249.58	204	10.13	1.30	7.77	0.94	44.6	35.3	17.3
1 13/16	284.82	240	9.98	1.81	7.62	1 28	46.0	35.8	14.9
1 13/16	221.98	180	10.15	1.83	8.06	1.34	41.8	23.5	13.1
1 13/16	221.98	180	10.13	1.81	....	....	....	11.1	6.2
1 13/16	172.43	120	10.13	1.81	8.43	1.38	36.6	15.7	13.1
1	361.68	312	10.04	0.99	8.22	0.71	41.2	47.1	15.1
1 1/4	258.68	228	7.01	1.27	5.31	0.90	46.3	38.2	16.8
1 3/4	478.88	432	8.03	1.75	....	....	....	52.7	12.2
1 3/4	236.28	168	8.03	1.75	6.22	1.18	47.8	22.1	13.2
1 3/4	240.28	180	8.03	1.75	7.44	1.60	15.3	20.1	11.2
1 1/4	478.88	432	8.00	1.26	....	....	....	51.7	12.0
1 1/4	236.99	156	8.00	1.26	6.29	0.94	41.37	25.8	16.5
1 1/4	238.18	168	8.00	1.26	6.41	0.85	45.9	18.2	10.8
1 3/16	254.63	216	7.98	1.20	6.14	0 92	41.0	33.2	15.4
2 5/16	338.58	300	8 03	2.32	6.34	1.77	39.8	34.6	11.5
1 3/16	258.68	216	7.00	1.18	5.27	0.85	45.8	36.8	17.0
2 5/16	338.58	300	9.00	2.31	....	....	10.5	35.3	11.8
1 1/4	206.58	168	9.09	1.25	6.81	0.83	50.3	39.1	23.3
1 1/4	205.38	168	9.09	1.25	6.94	0.94	42.6	34.8	20.7
1 5/16	409.08	348	6.07	1.18	....	....	....	19.5	5.6
1 3/16	416.78	360	6.04	1.18	....	....	....	21.6	6.0
1 3/16	422.18	372	4.03	0.80	3.25	0.57	42.6	39.2	10.5
1	421.88	372	4.02	1.00	3.10	0.75	41.8	45.1	12.1
1 1/4	423.68	372	4.04	1.13	3.08	0.79	46.8	47.8	12.8
1 13/16	279.98	240	8.11	1.79	6.26	1.34	42.2	37.1	15.5
1 13/16	279.88	240	8.11	1.79	6.13	1.24	47.7	38.8	16.2
1	289.23	252	7.02	1.00	5.53	0.75	40.9	44.9	17.8
1	249.48	252	7.00	1.00	5.51	0.67	47.3	42.7	16.9

APPENDIX D.

s of Steel Eye-Bars.

Results of Mechanical Tests.				Tests on Sample Bars from same					
ation.	Elastic Limit	Max. Load.	Place of Fracture.	Melt Number.	Areas.		Reduction.	Elongation.	Ela
					Original. Inches.	After testing. Inches.			
Percent.	Lbs. per sq. in.	Lbs. per sq. in.					Percent.	Percent.	Lbs.
16.8	35 100	67 490	Body	6 552	.9500	.4992	47.5	27.5	
8.96	36 030	65 190	Head	6 552					
8.2	37 680	70 160	Body	10 747	.9918	.4593	52.6	24.4	
11.8	39 700	65 500	"	10 647	.9620	.4957	47.9	28.8	
17.3	33 140	65 060	"	6 552	.9500	.4992	47.5	27.5	
13.4	29 690	56 700	"	10 830	.9756	.5380	45.4	28.1	
13.8	30 800	59 210	"	10 830					
13.5	32 860	65 600	"	09 099	1.1590	.6474	44.5	20.0	
15.3	31 110	61 060	"	5 798	1 0140	.5814	42.7	28.8	
13.7	33 990	63 220	"	10 886	.9868	.4719	52.2	28.1	
13.5	29 330	63 100	"	015 014	.9635	.4983	48.3	28.8	
15.2	28 660	63 860	"	015 014	.....	....	....	....	
2.5	31 970	53 860	"	015 090	1.0201	.6084	40.4	27.0	
3.2	.....	58 950	Head	015 090					
21.5	30 270	51 500	Body	11 045	1.0180	.4941	51.5	28.8	
6.9	28 080	55 160	"	11 063	1.1220	.6371	43.2	24.2	
19.2	.....	62 590	"	11 063					
14.1	29 670	62 140	"	015 094	1.0200	.4121	59.6	26.3	
2.8	29 270	49 340	Head	015 094					
3.6	.....	53 930	"	015 094					
11.8	32 700	65 400	Body	015 093	1.0670	.6374	40.3	25.0	
11.3	31 290	64 510	"	015 093					
22.5	28 980	52 010	"	8 368	1.1700	.5133	34.2	31.3	
13.6	28 410	54 740	"	6 961	1.0170	.5220	48.7	28.1	
19.3	30 500	58 870	"	40 411	.9338	.5572	40.3	25.0	
9.6	29 980	56 950	"	40 411					
12.3	33 360	73 550	"	5 868	.9700	.4792	51.5	25.5	
15.7	32 520	60 710	"	40 435	9504	.5363	43.6	27.0	
17.3	31 900	59 470	"	40 435					
14.9	28 000	58 720	"	013 091	1.0000	.5557	44.4	29.5	
13.1	32 290	62 270	"	40 409	.9746	.5574	42.8	21.3	
6.2	31 910	58 050	Head	40 409					
13.1	.....	65 170	Body	40 409					
15.1	29 970	58 680	"	40 414	1.1720	.6371	45.7	27.0	
16.8	28 640	56 830	"	11 072	1.0200	.5402	47.0	28.1	
12.2	32 220	61 260	Not broken	10 770	1.0020	.6013	40.0	28.1	
13.2	.....	54 720	Body	10 770					
11.2	.....	57 190	"	10 770					
12.0	32 380	62 930	Not broken	10 770					
16.5	.....	68 590	Body	10 770					
10 8	.....	58 880	"	10 770					
15.4	31 930	63 870	"	10 828	1.0100	.4108	59.3	21.9	
11.5	32 840	62 400	"	10 660	1.0620	.5946	44.0	23.1	
17.0	27 870	53 520	"	20 816	1.0560	.4995	52.7	31.9	
11.8	27 730	54 400	Not broken	09 257	1.0900	.5416	50.3	29.5	
23.3	32 590	57 410	Body	09 405	.9734	.4488	53.8	28.7	
20.7	32 820	58 440	"	09 405					
5.6	35 480	60 390	In upset for screw.	3 055	.830	.435	47.6	23.0	
6.0	39 190	63 220	Sleeve nut	3 327	.672	.303	54.9	27.5	
10.6	40 540	71 580	Body	3 095	1.026	.436	58.5	31.3	
12.1	39 570	68 490	"	3 095	.....	....	....	....	
12.8	39 720	69 180	"	3 095	.....	....	....	....	
15.5	28 940	58 010	"	11 150	1.114	.5960	46.5	23.0	
16.2	28 660	58 290	"	11 150					
17.8	31 380	59 850	"	11 072	1.020	.5402	47.0	28.1	
16.9	31 470	59 730	"	11 072					

APPENDIX D.

Tests of Steel Eye-Bars.

Results of Mechanical Tests.					Tests on Sample Bars f				
Elongation.		Elastic Limit	Max. Load.	Place of Fracture.	Melt Number.	Areas.		Reduction.	Elonga
es.	Percent.	Lbs. per sq. in.	Lbs. per sq. in.			Original. Inches.	After testing. Inches.	Percent.	Perce
2	16.8	35 100	67 490	Body	6 552	.9500	.4992	47.5	27.
75	8.96	36 630	65 190	Head	6 552				
6	8.2	37 680	70 160	Body	10 747	.9918	.4593	52.6	24.
8	11.8	39 700	65 500	"	10 647	.9520	.4957	47.9	28.
5	17.3	33 140	65 060	"	6 552	.9500	.4992	47.5	27.
7	13.4	29 690	56 700	"	10 830	.9756	.5330	45.4	28.
6	13.8	30 800	59 210	"	10 830				
5	13.5	32 860	65 600	"	09 099	1.1590	.6474	44.5	20.
8	15.3	31 110	61 060	"	5 798	1 0140	.5814	42.7	28.
9	13.7	33 990	63 220	"	10 886	.9868	.4719	52.2	28.
0	13.5	29 330	63 100	"	015 014	.9635	.4983	48.3	28.
6	15.2	28 660	63 860	"	015 014	.....	....	....	....
4	2.5	31 970	53 860	"	015 090	1.0201	.6084	40.4	27.
7	3.2	.....	58 950	Head	015 090				
3	21.5	30 270	51 500	Body	11 045	1.0180	.4941	51.5	28.
8	6.9	28 080	55 160	"	11 063	1.1220	.6371	43.2	24.
4	19.2	.....	62 590	"	11 063				
9	14.1	29 670	62 140	"	015 094	1.0200	.4121	59.6	26.
7	2.8	29 270	49 340	Head	015 094				
2	3.6	.....	53 930	"	015 094				
0	11.8	32 700	65 400	Body	015 093	1.0670	.6374	40.3	25.
0	11.3	31 290	64 510	"	015 093				
3	22.5	28 980	52 010	"	8 368	1.1700	.5133	34.2	31.
3	13.6	28 410	54 740	"	6 961	1.0170	.5220	48.7	28.
4	19.3	30 500	58 870	"	40 411	.9338	.5572	40.3	25.
6	9.6	29 980	56 950	"	40 411				
8	12.3	33 360	73 550	"	5 868	.9700	.4792	51.5	25.
0	15.7	32 520	60 710	"	40 435	9504	.5363	43.6	27.
3	17.3	31 900	59 470	"	40 435				
8	14.9	28 000	58 720	"	013 091	1.0000	.5557	44.4	29.
5	13.1	32 290	62 270	"	40 409	.9746	.5574	42.8	21.
1	6.2	31 910	58 050	Head	40 409				
7	13.1	.....	65 170	Body	40 409				
1	15.1	29 970	58 680	"	40 414	1.1720	.6371	45.7	27.
2	16.8	28 640	56 830	"	11 072	1.0200	.5402	47.0	28.
7	12.2	32 220	61 260	Not broken	10 770	1.0020	.6013	40.0	28.
1	13.2	.....	54 720	Body	10 770				
1	11.2	.....	57 190	"	10 770				
7	12.0	32 380	62 930	Not broken	10 770				
8	16.5	.....	68 590	Body	10 770				
2	10.8	.....	58 880	"	10 770				
2	15.4	31 930	63 870	"	10 828	1.0100	.4108	59.3	21
6	11.5	32 840	62 400	"	10 660	1.0620	.5946	44.0	23
8	17.0	27 870	53 520	"	20 816	1.0560	.4995	52.7	31
3	11.8	27 730	54 400	Not broken	09 257	1.0900	.5416	50.3	29
1	23.3	32 590	57 410	Body	09 405	.9734	.4488	53.8	28
8	20.7	32 820	58 440	"	09 405				
5	5.6	35 480	60 390	In upset for screw.	3 055	.830	.435	47.6	23
6	6.0	39 190	63 220	Sleeve nut	3 327	.672	.303	54.9	27
2	10.6	40 540	71 580	Body	3 095	1.026	.436	58.5	31
1	12.1	39 570	68 490	"	3 095	.....	....	....	..
8	12.8	39 720	69 180	"	3 095	.....	....	....	..
1	15.5	28 940	58 010	"	11 150	1.114	.5960	46.5	23
8	16.2	28 660	58 290	"	11 150				
9	17.8	31 380	59 850	"	11 072	1.020	.5402	47.0	28
7	16.9	31 470	59 730	"	11 072				

IPLE BARS FROM SAME MELTS.

on. nt.	Elongation. Percent.	Elastic Limit. Lbs. per sq. in.	Max. Load. Lbs. per sq. in.	Phosphorus. Percent.	KIND OF STEEL.	MADE BY—	FORGED BY—
	27.5	41 580	73 050	.027	Basic open-hearth..	Carnegie, Phipps & Co..	Union Bridge Co.
	24.4	42 650	75 620	.015	" " " ..	" " " .	" " "
	28.8	40 280	70 280	.062	" " " ..	" " " .	" " "
	27.5	41 580	73 050	.027	" " " ..	" " " .	" " "
	28.1	40 490	69 700	.026	" " " ..	" " " .	" " "
	20.0	43 750	75 000	.021	" " " ..	" " " .	" " "
	28.8	42 210	69 730	.046	" " " ..	" " " .	" " "
	28.1	40 230	69 720	.025	" " " ..	" " " .	" " "
	28.8	38 090	71 300	.017	" " " ..	" " " .	" " "
	....	.....	.....	....			
	27.0	40 200	71 860	.017	" " " ..	" " " .	" " "
	28.8	33 400	57 170	.014	" " " ..	" " " .	Keystone " "
	24.2	38 320	70 220	.023	" " " ..	" " " .	Union " "
	26.3	40 200	71 080	.028	" " " ..	" " " .	" " "
	25.0	39 360	69 360	.041	" " " ..	" " " .	" " "
	31.3	34 190	58 460	.039	" " " ..	" " " .	Keystone " "
	28.1	41 400	67 840	.010	" " " ..	" " " .	Union " "
	25.0	40 910	70 360	.014	" " " ..	" " " .	" " "
	25.5	40 410	69 900	.063	" " " ..	" " " .	" " "
	27.0	40 400	70 490	.023	" " " ..	" " " .	" " "
	29.5	40 000	66 800	.008	" " " ..	" " " .	" " "
	21.3	40 530	72 240	.056	" " " ..	" " " .	" " "
	27.0	40 610	70 480	.060	" " " ..	" " " .	" " "
	28.1	40 790	68 730	.030	" " " ..	" " " .	" " "
	28.1	40 920	76 150	.042	" " " ..	" " " .	" " "
	21.9	40 900	69 800	.024	" " " ..	" " " .	" " "
	23.1	41 710	71 000	.066	" " " ..	" " " .	" " "
	31.9	32 480	58 050	.027	" " " ..	" " " .	Pencoyd B. & C. Co.
	29.5	39 900	66 780	.013	" " " ..	" " " .	Keystone Bridge Co.
	28.7	38 110	60 920	.014	" " " ..	" " " .	" " "
	23.0	39 760	74 340	.069	Acid " " ..	Pencoyd L. & S. Co.....	Pencoyd B. & C. Co.
	27.5	41 670	71 740	.082	" " " ..	" " "	" " "
	31.3	39 280	66 090	.084	" " " ..	" " "	" " "
	....	.....	.....	....	" " " ..	" " "	" " "
	....	.....	.....	....	" " " ..	" " "	" " "
	23.0	40 480	66 880	.030	Basic " " ..	Carnegie, Phipps & Co..	Union Bridge Co....
	28.1	40 790	68 730	.030	" " " ..	" " " .	" "

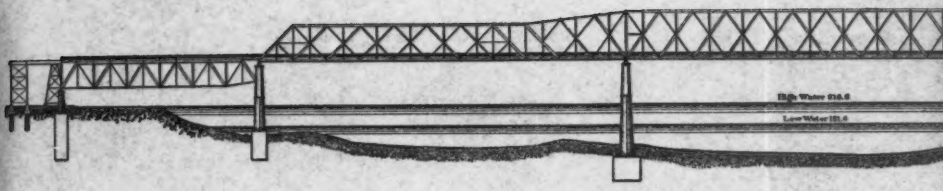
K.C.&M.R.&B.C

MEMPHIS BRI

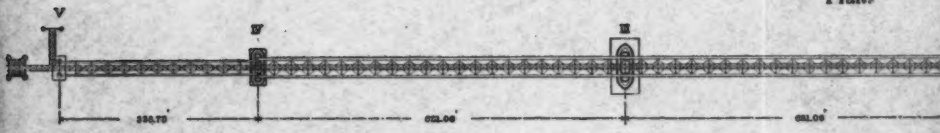
GENERAL ELEVATION A

Scale.

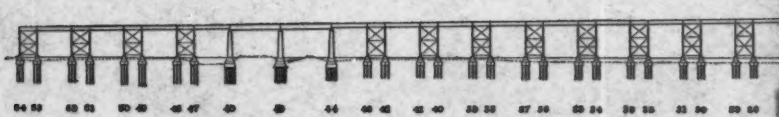
Elevation.



Plan.



Elevation.



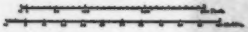
Plan.

K.C.&M.R.&B.Co.

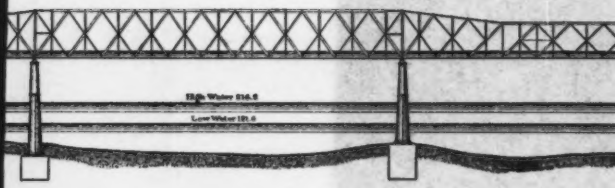
MEMPHIS BRIDGE.

GENERAL ELEVATION AND PLAN.

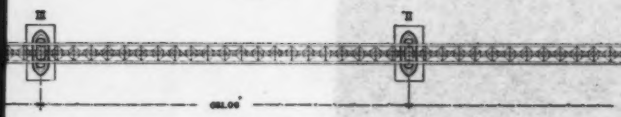
Scale.



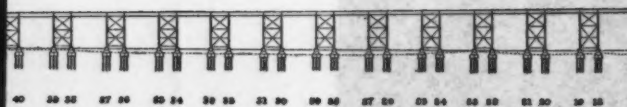
Elevation.



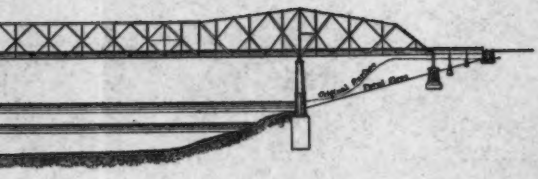
Plan.

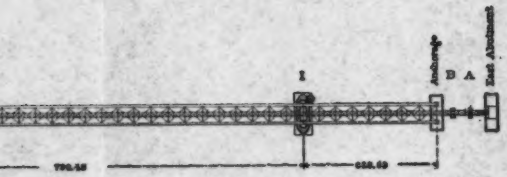


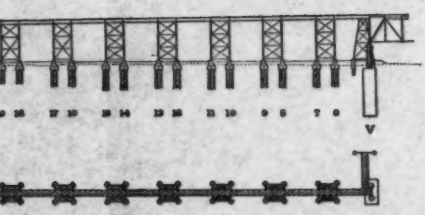
Elevation.



Plan.




I
Anchorage
East Abutment
B A
790.50
938.50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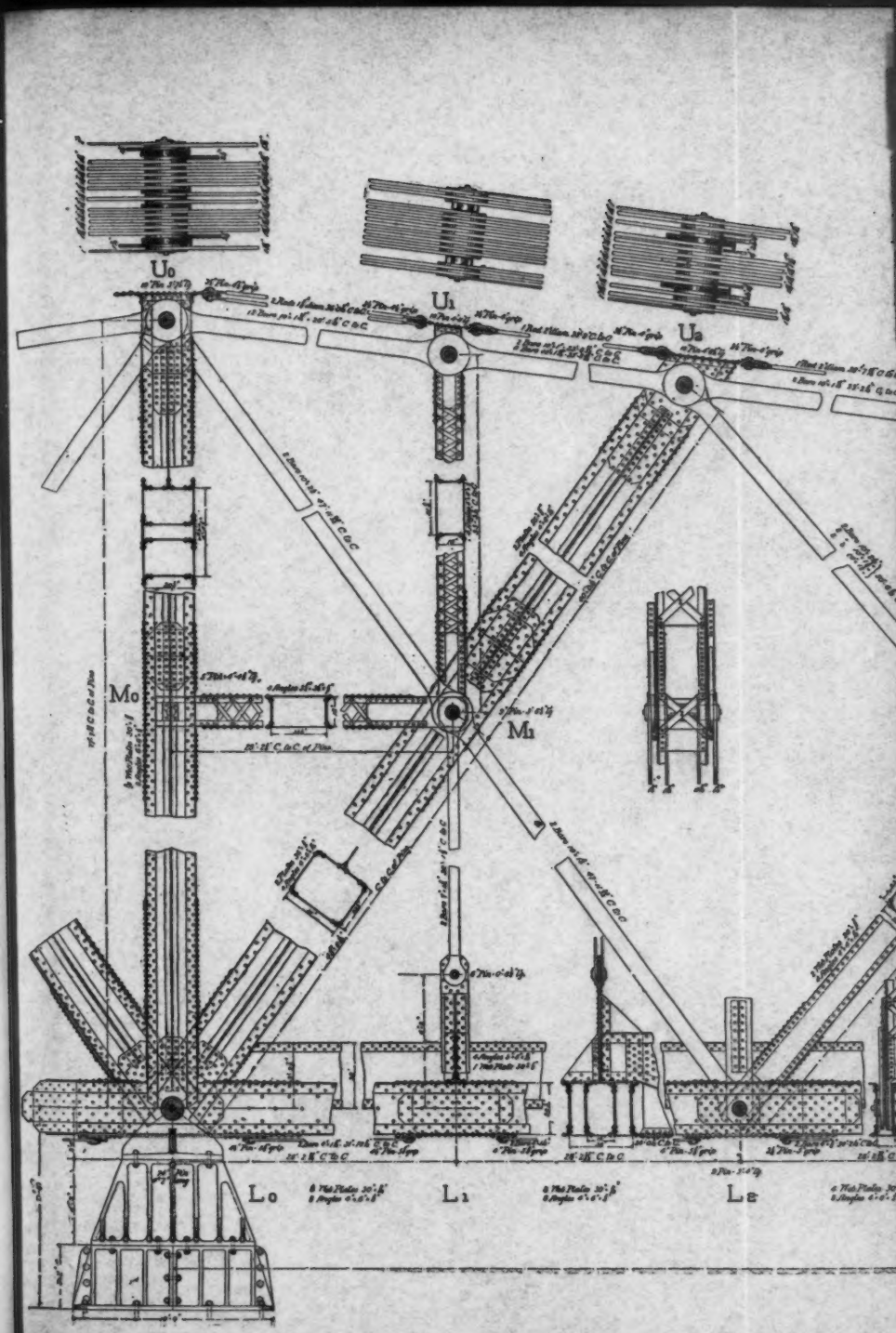
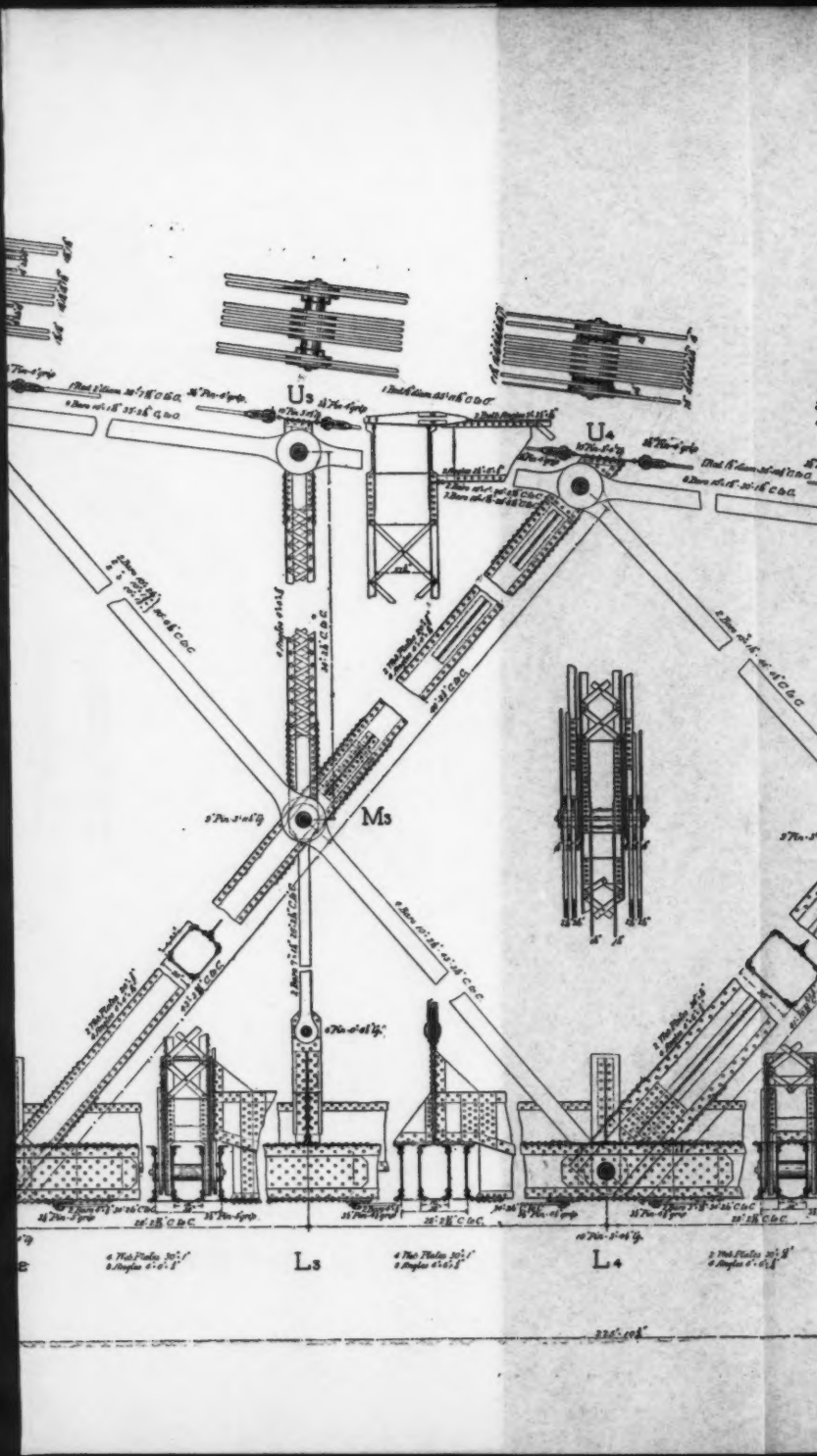
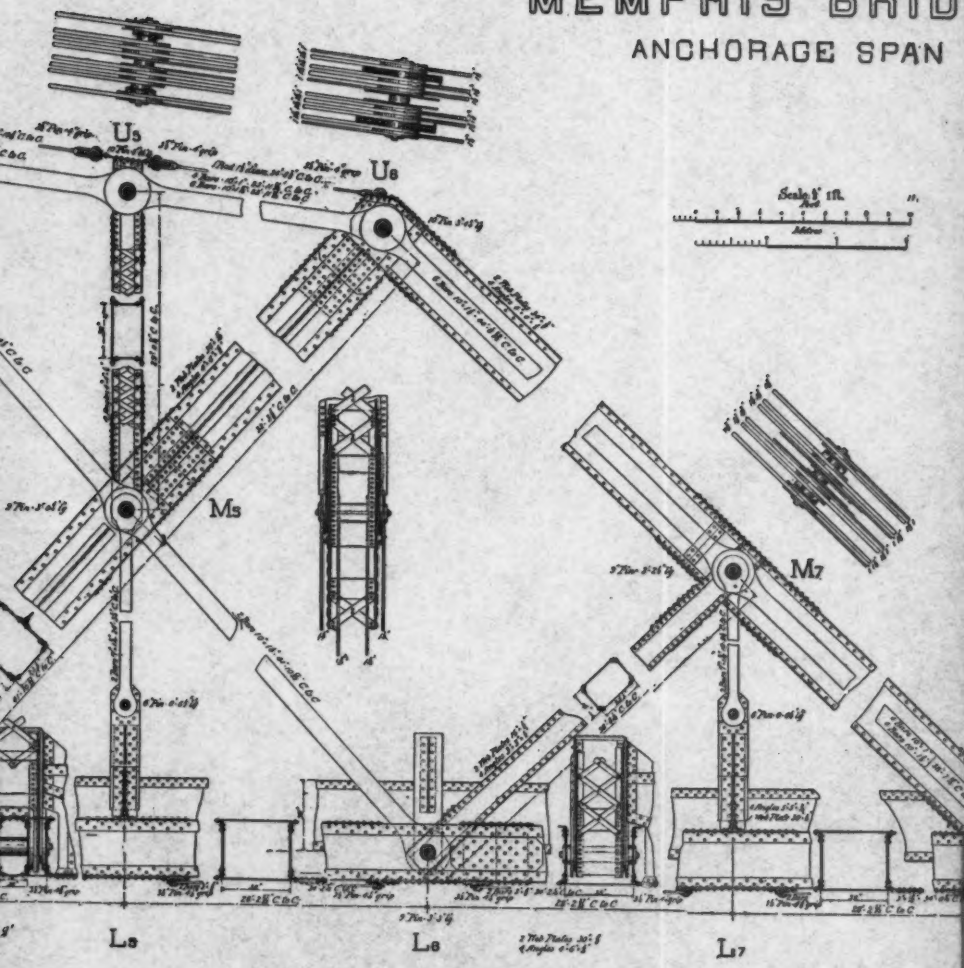

U0
U1
U2
M0
M1
L0
L1
L2


U3
U4
M3
L3
L4

KC & M.R.& B Co.

MEMPHIS BRID

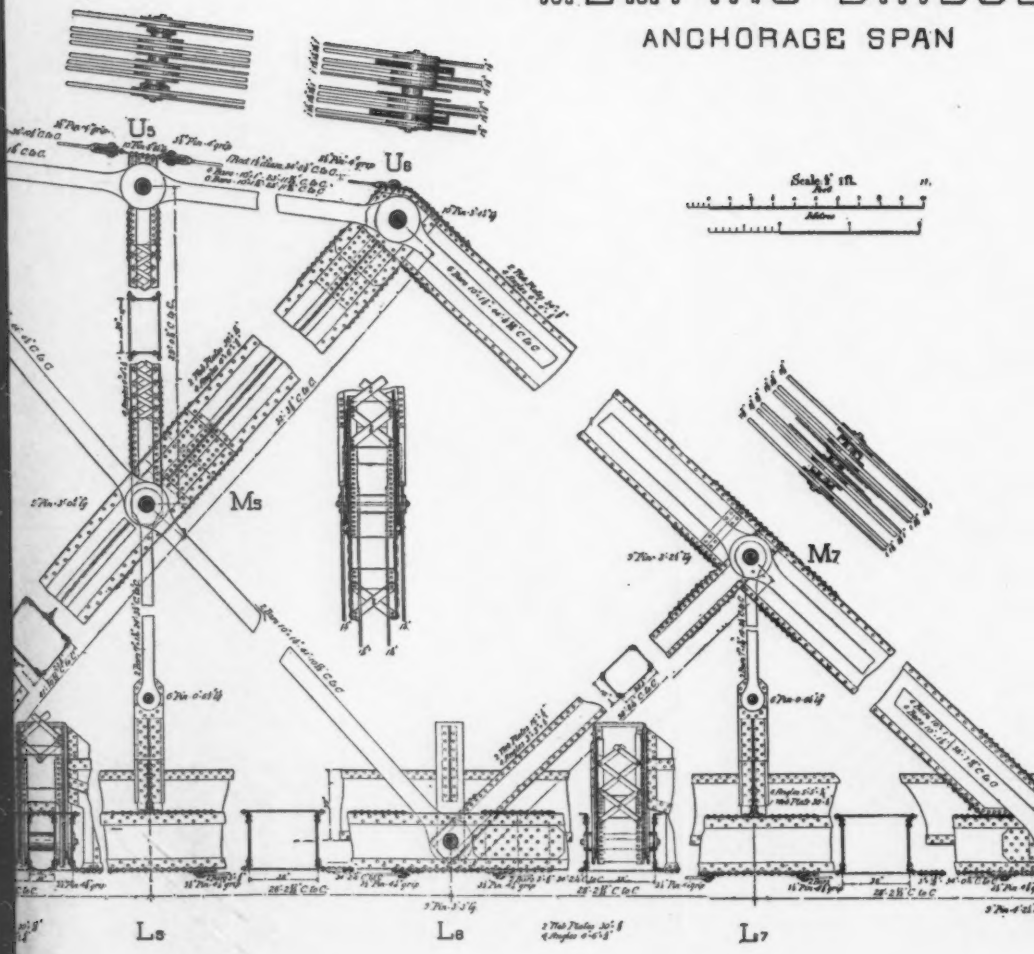
ANCHORAGE SPAN



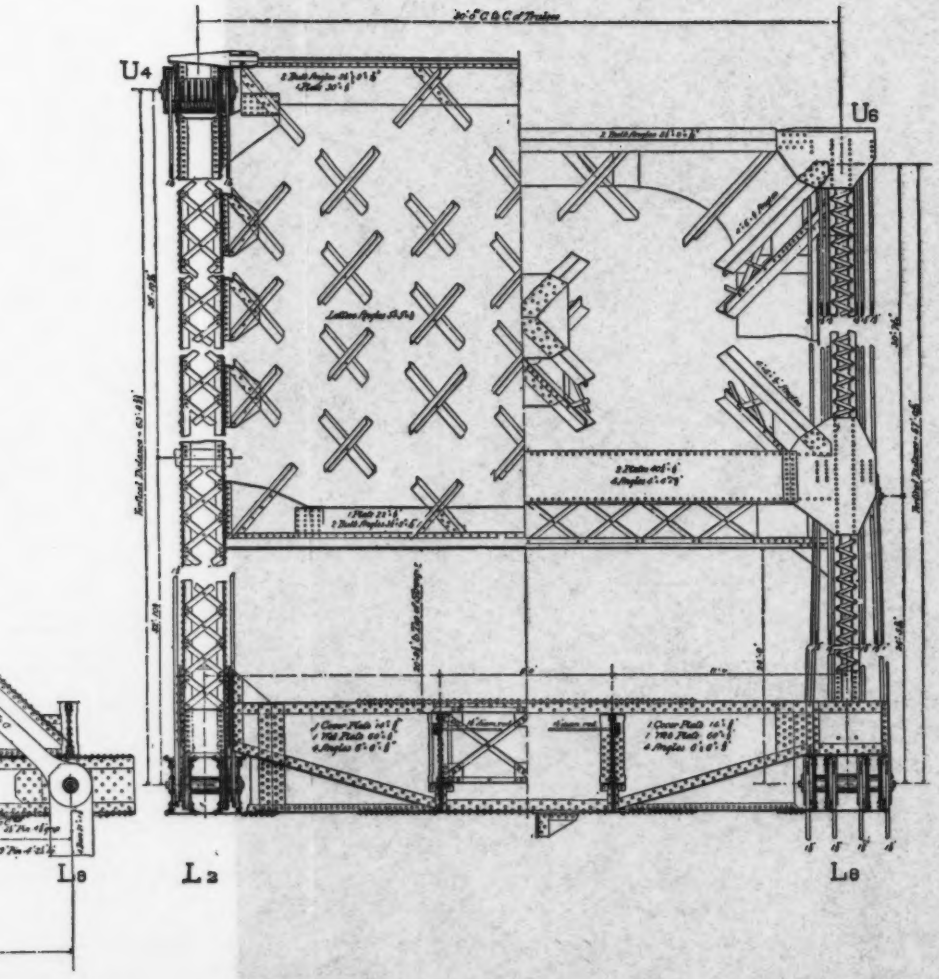
K.C. & M.R. & B. Co.

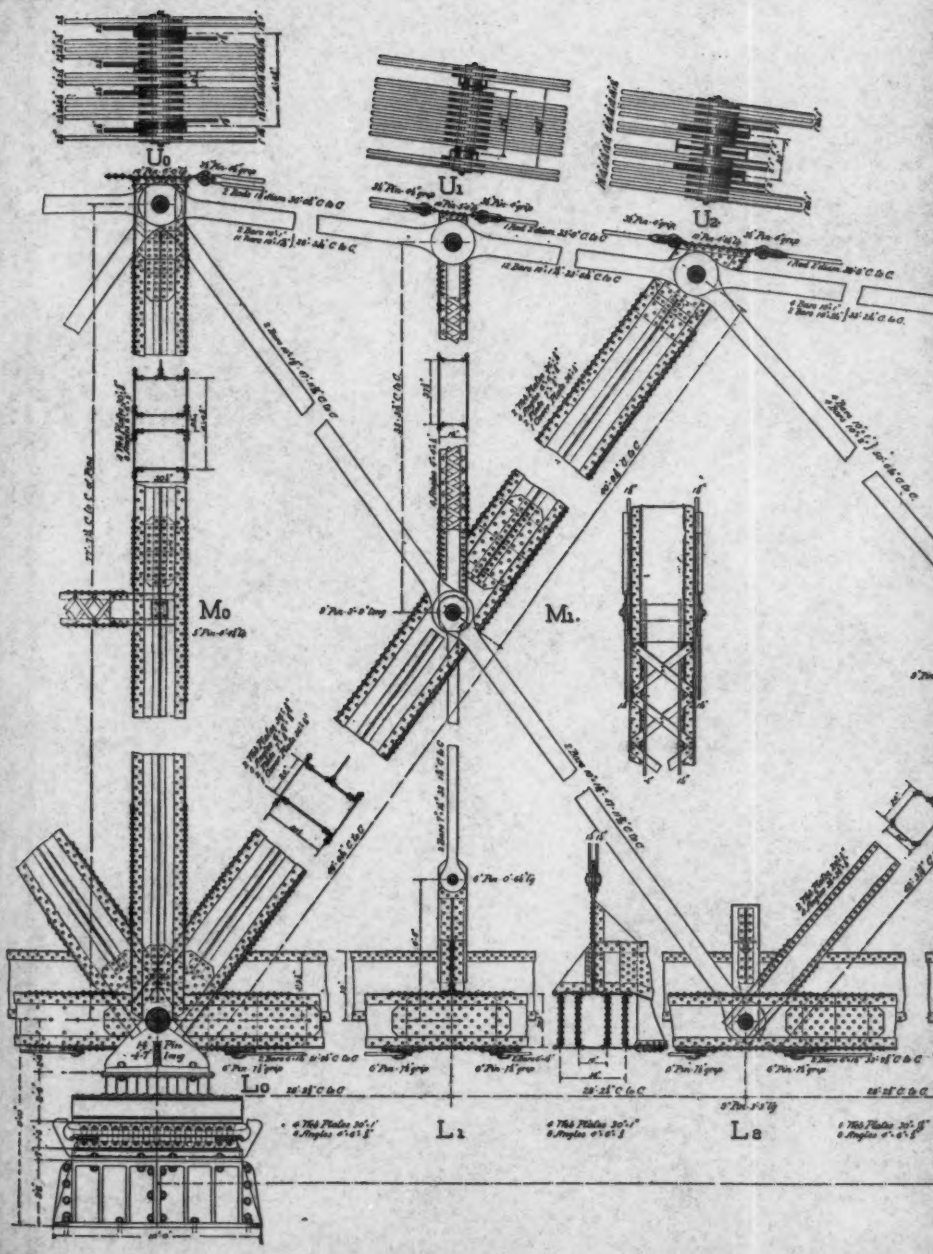
MEMPHIS BRIDGE

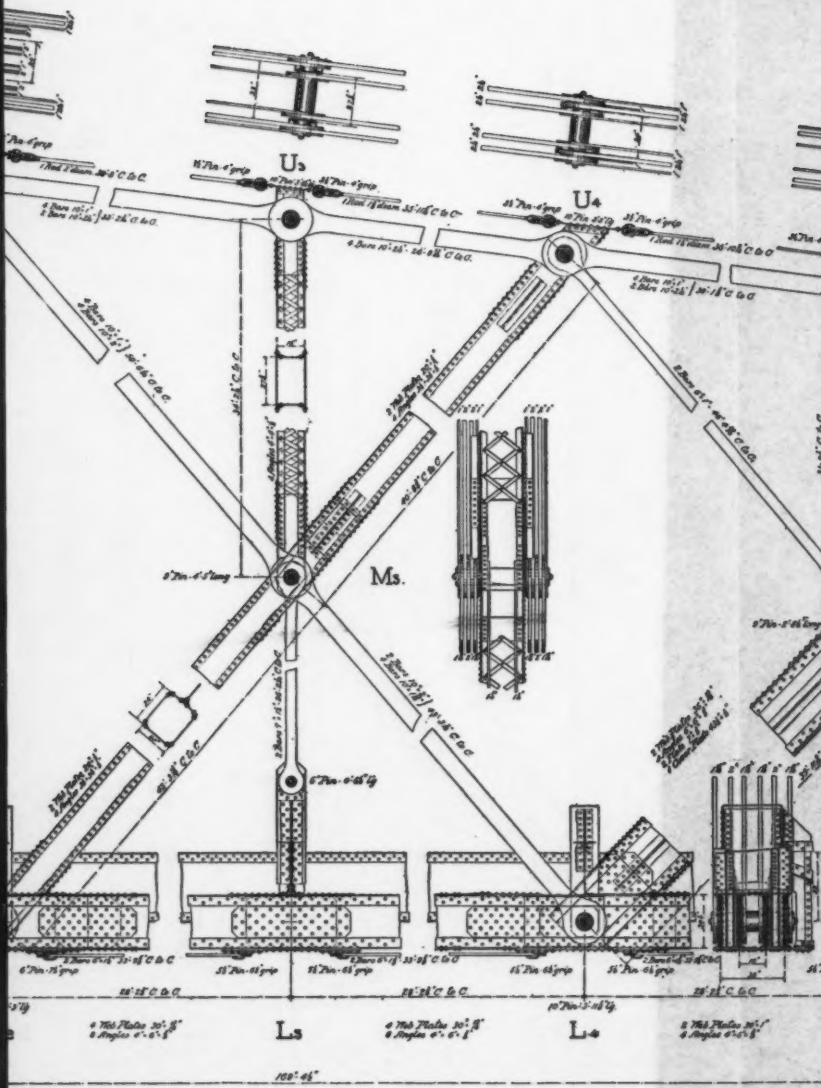
ANCHORAGE SPAN



GE.



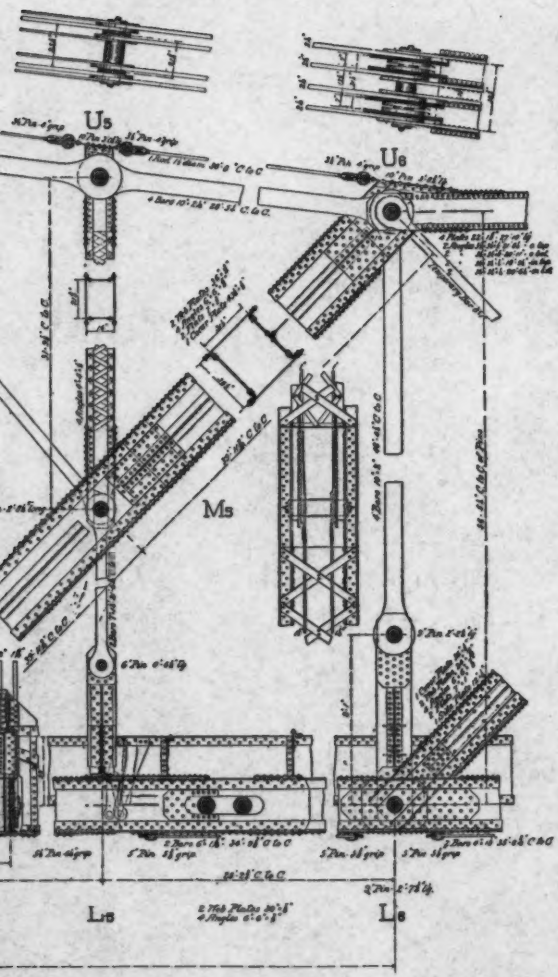

U0
U1
U2
M0
M1
L0
L1
L2

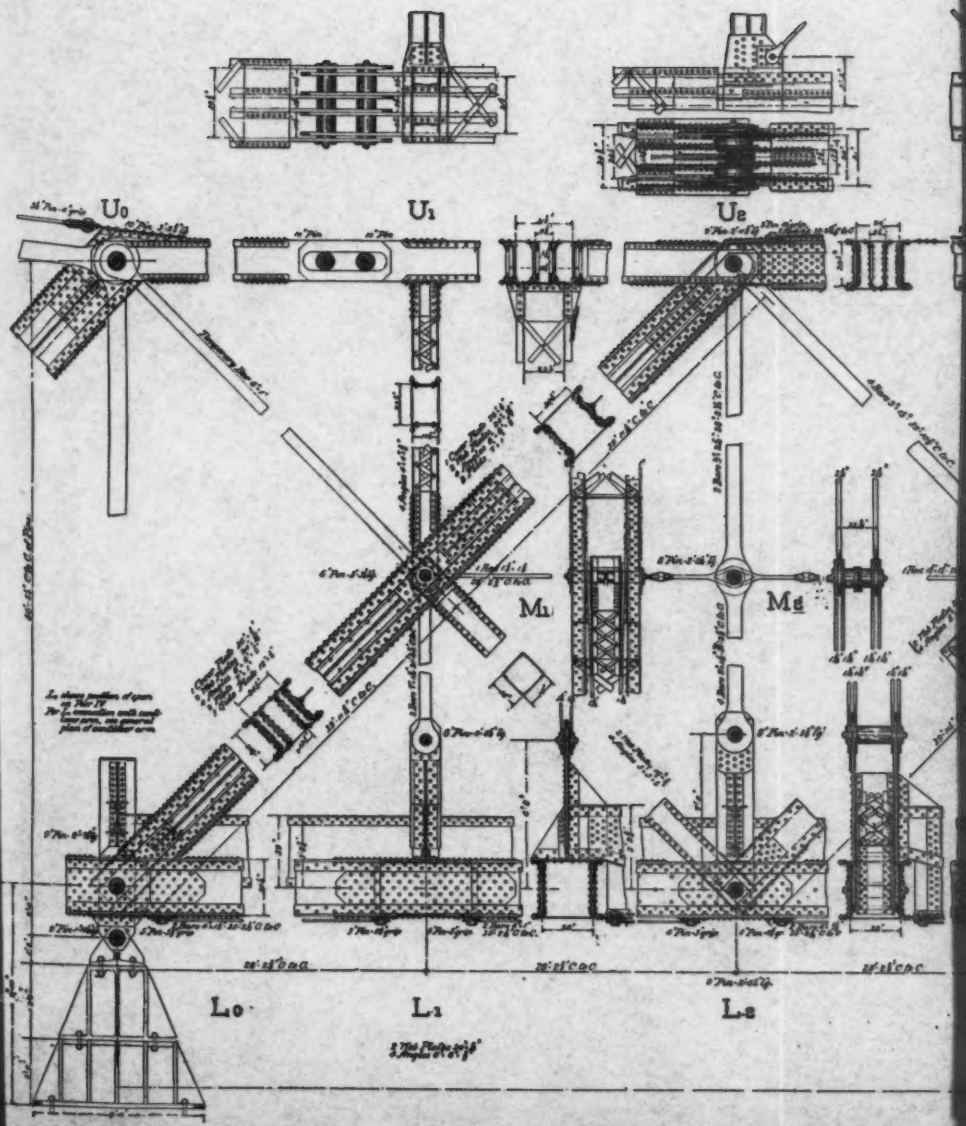

U3
U4
Ms.
L3
L4

KC & MR. & B. Co.

MEMPHIS BRIDGE.

CANTILEVER ARM.

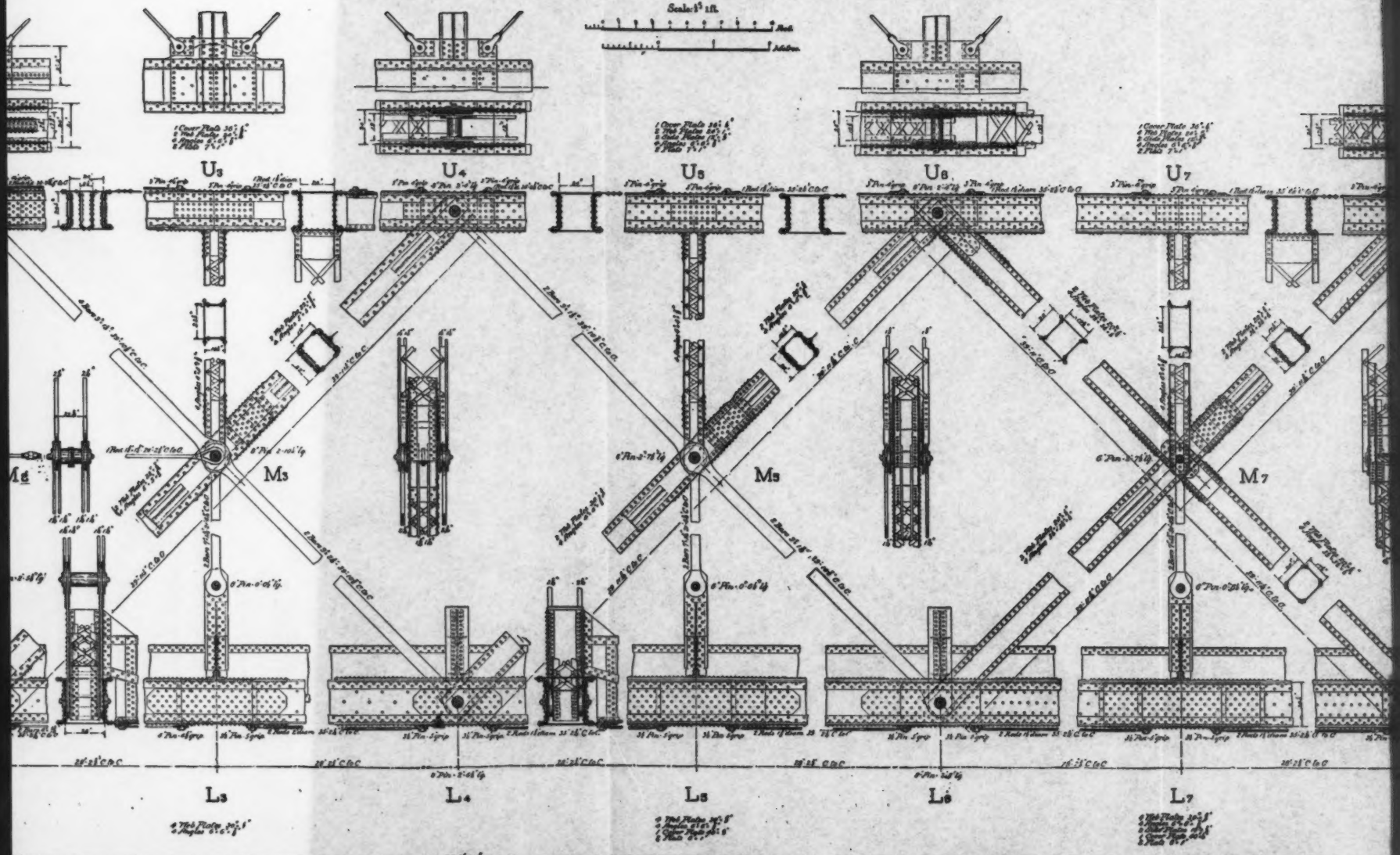



U0
U1
U2
M1
M2
L0
L1
L2

K.C.&M.R.&B.C.o

MEMPHIS BRIDGE.

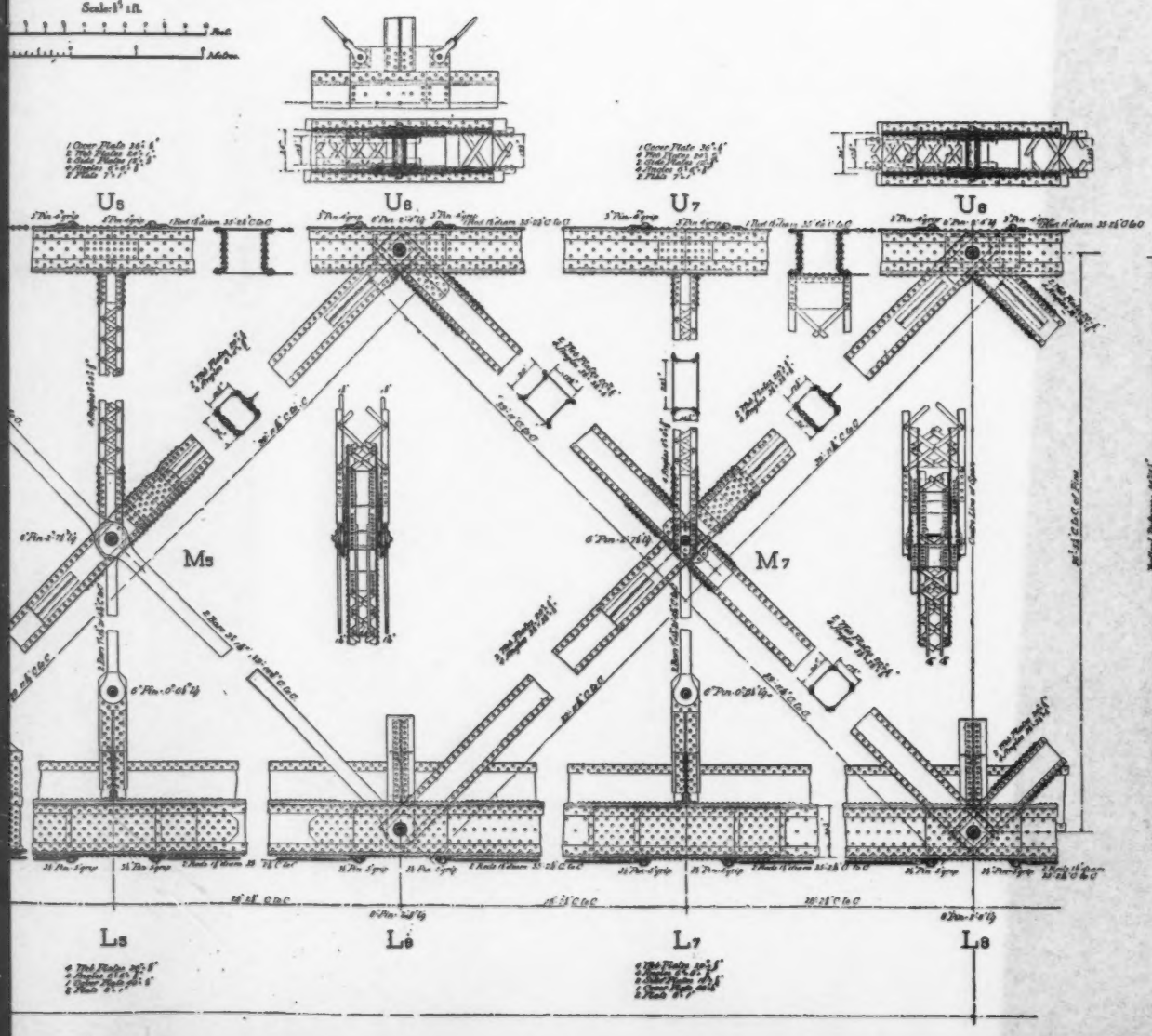
INTERMEDIATE SPAN

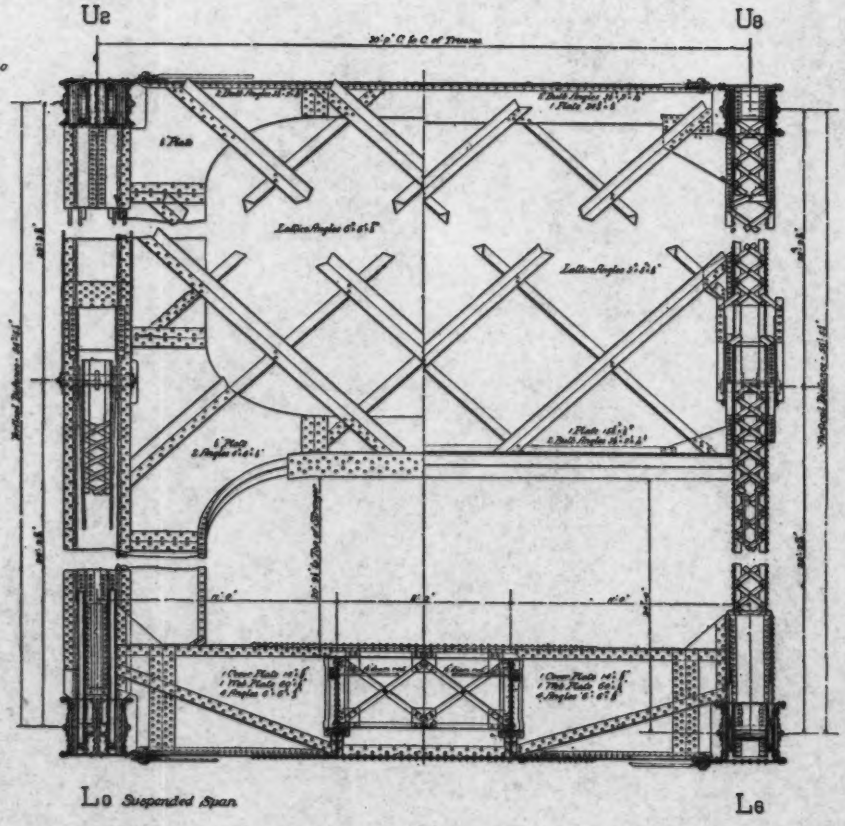


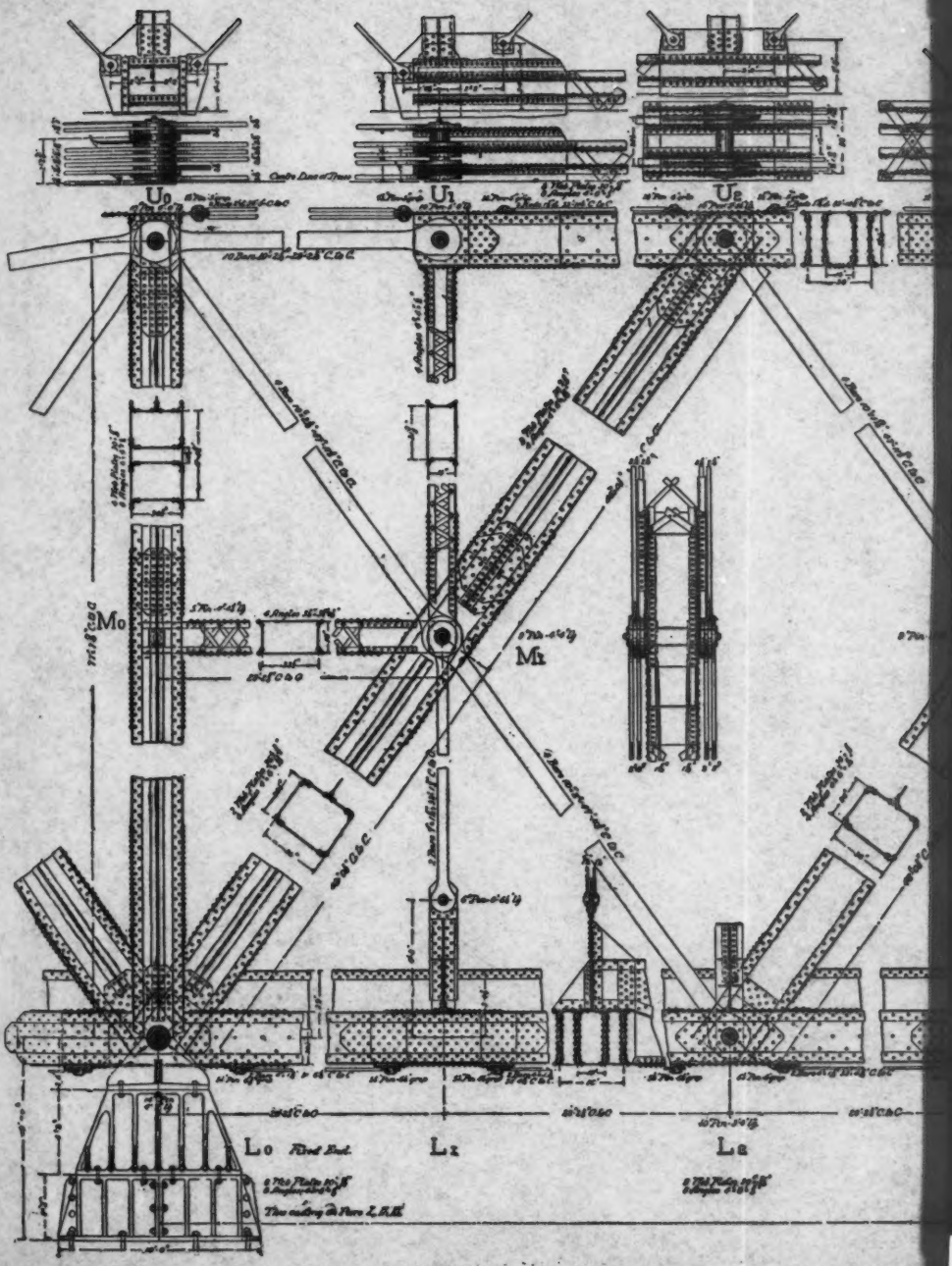
K.C.&M.R.&B.C.o

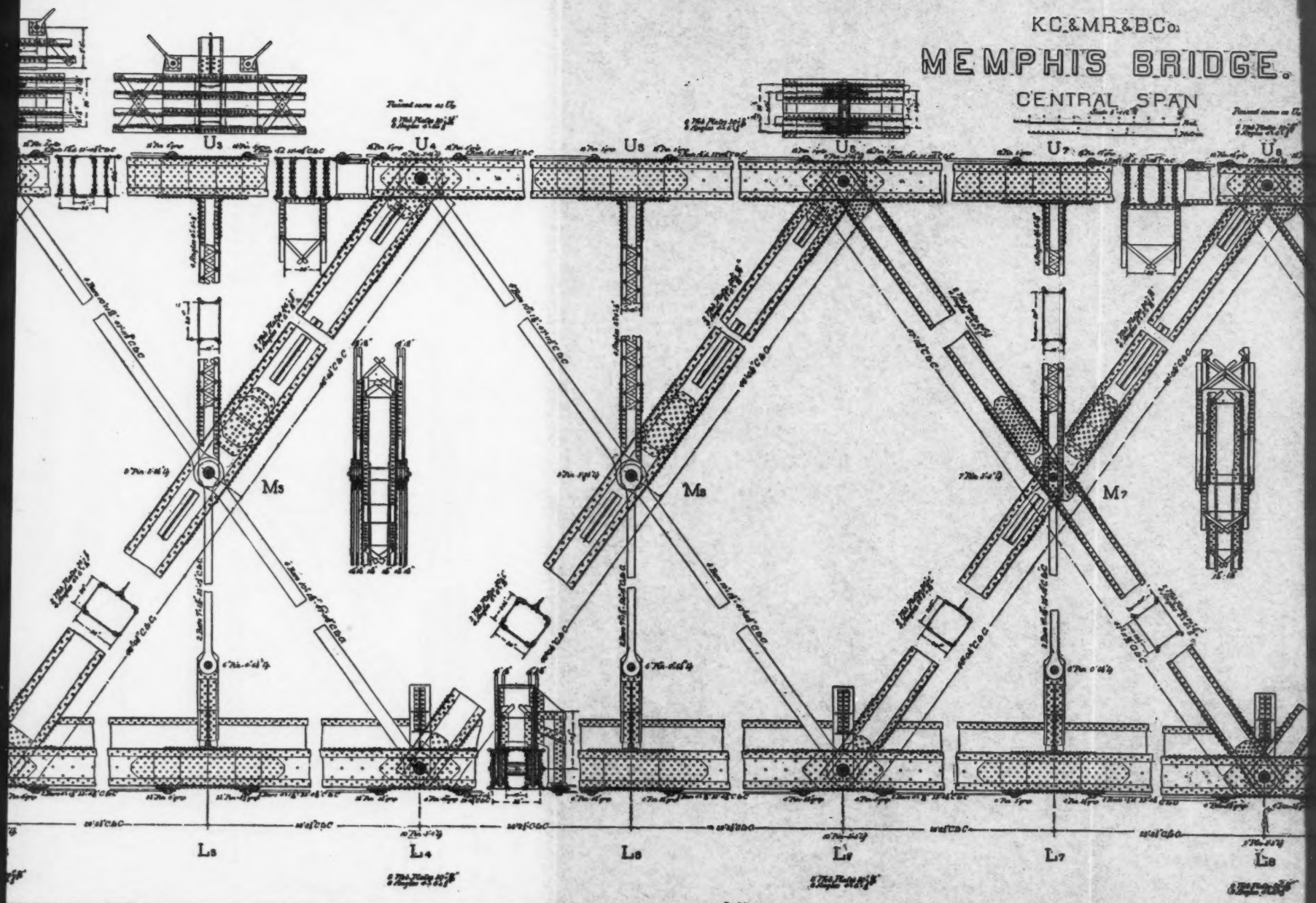
PHIS BRIDGE.

ERMEDIATE SPAN





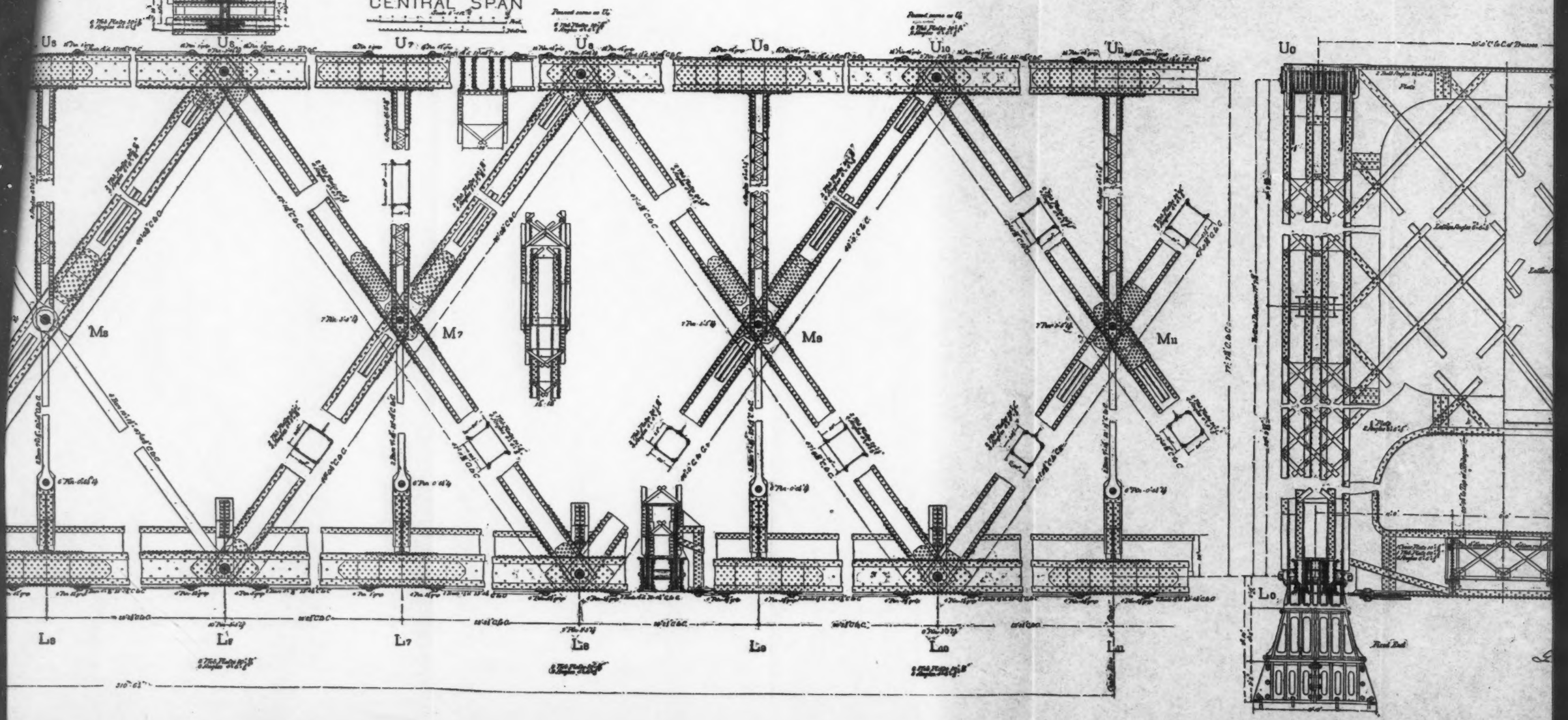

U0
U1
U2
M0
M1
L0
L1
L2


K.C.&M.R.&B.Co.
MEMPHIS BRIDGE.
CENTRAL SPAN
U3
U4
U5
U6
U7
U8
M5
M6
M7
L3
L4
L5
L6
L7
L8

K.C.&M.R.&B.Co.

MEMPHIS BRIDGE.

CENTRAL SPAN

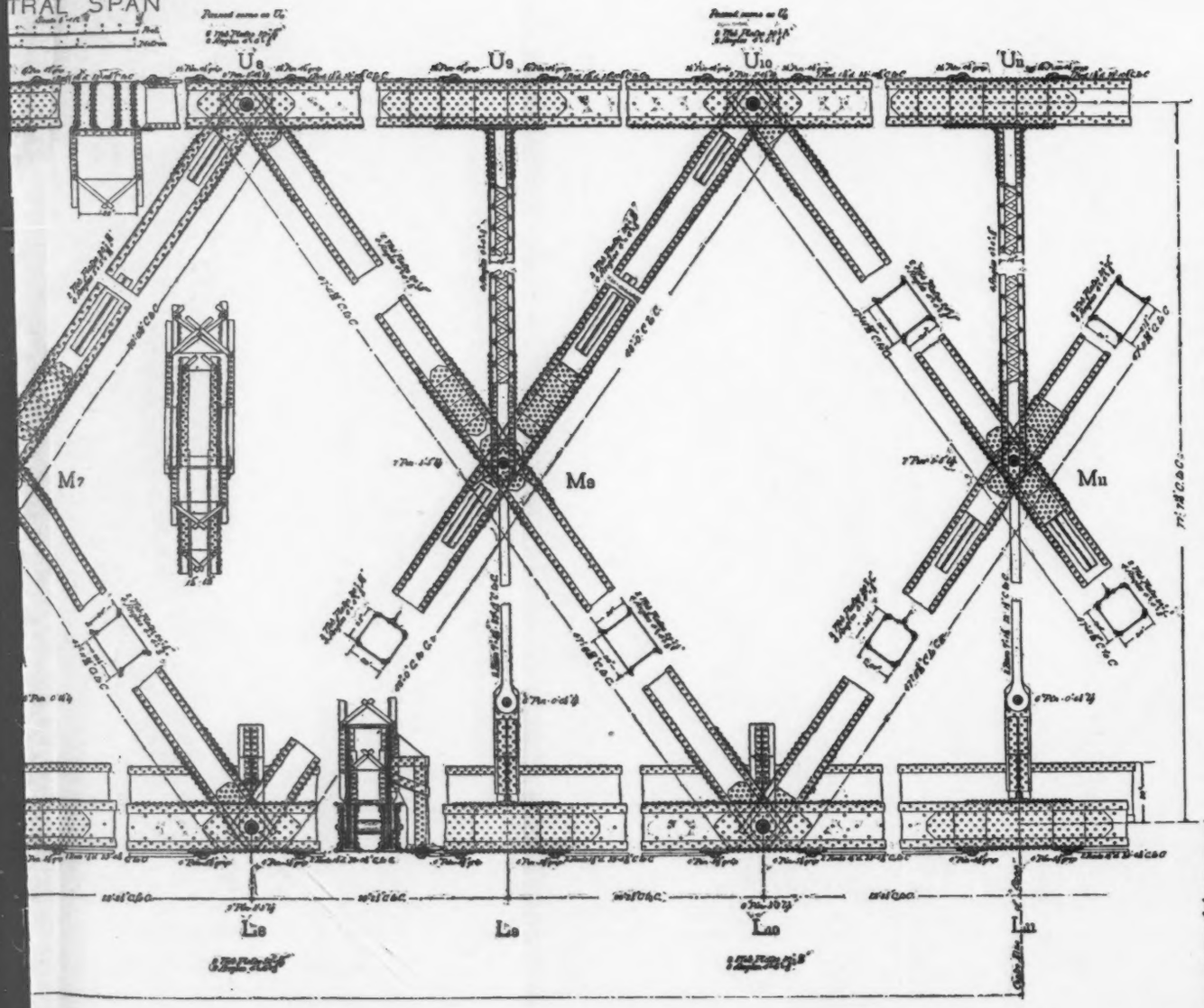


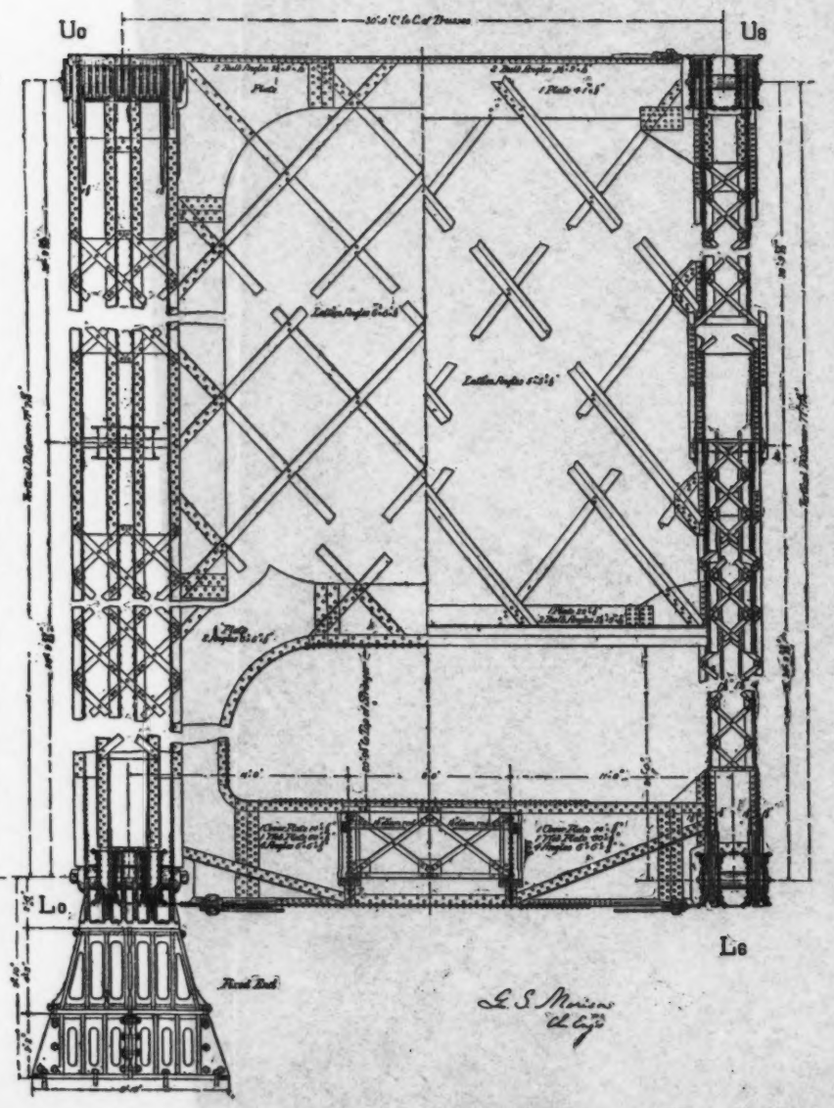
VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE V.

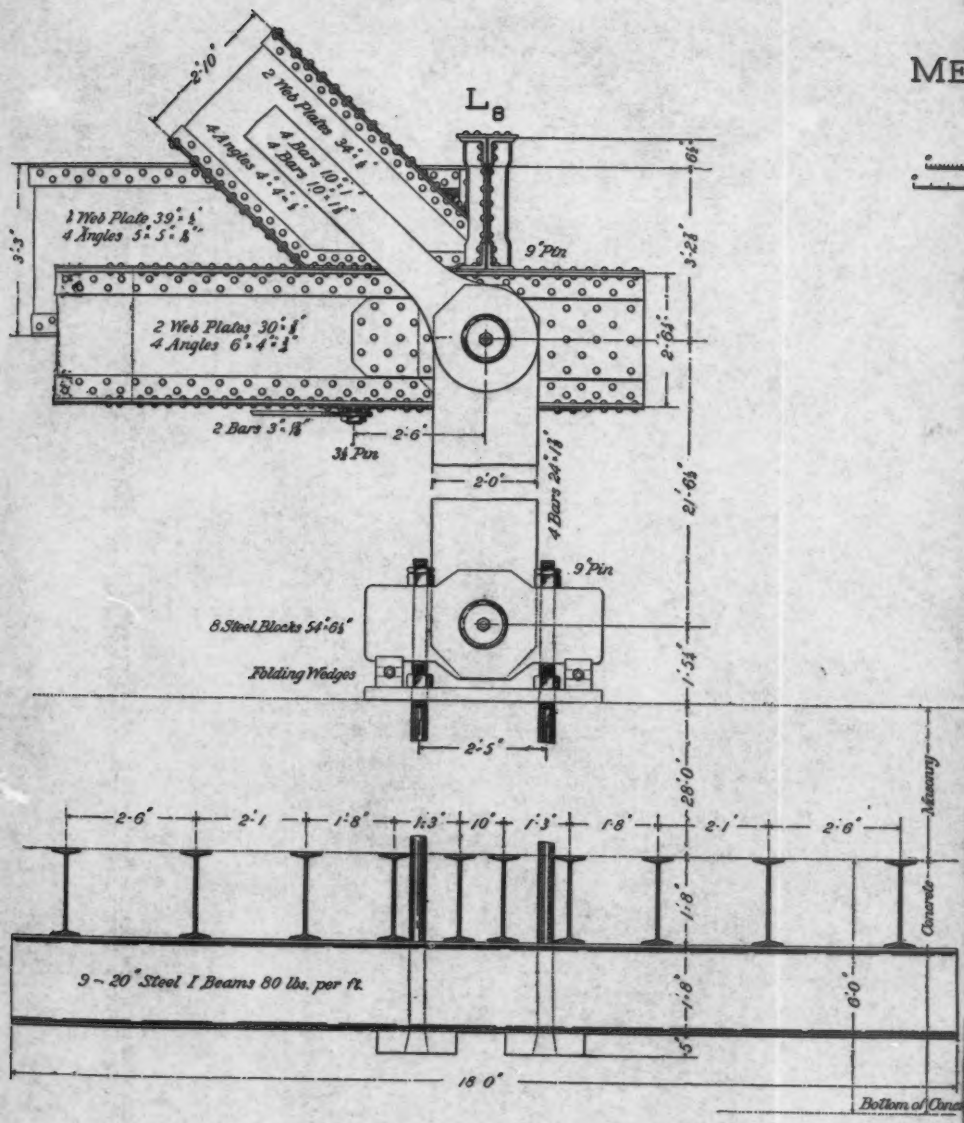
T&M.R.&B.Co.

IS BRIDGE.

TRAL SPAN





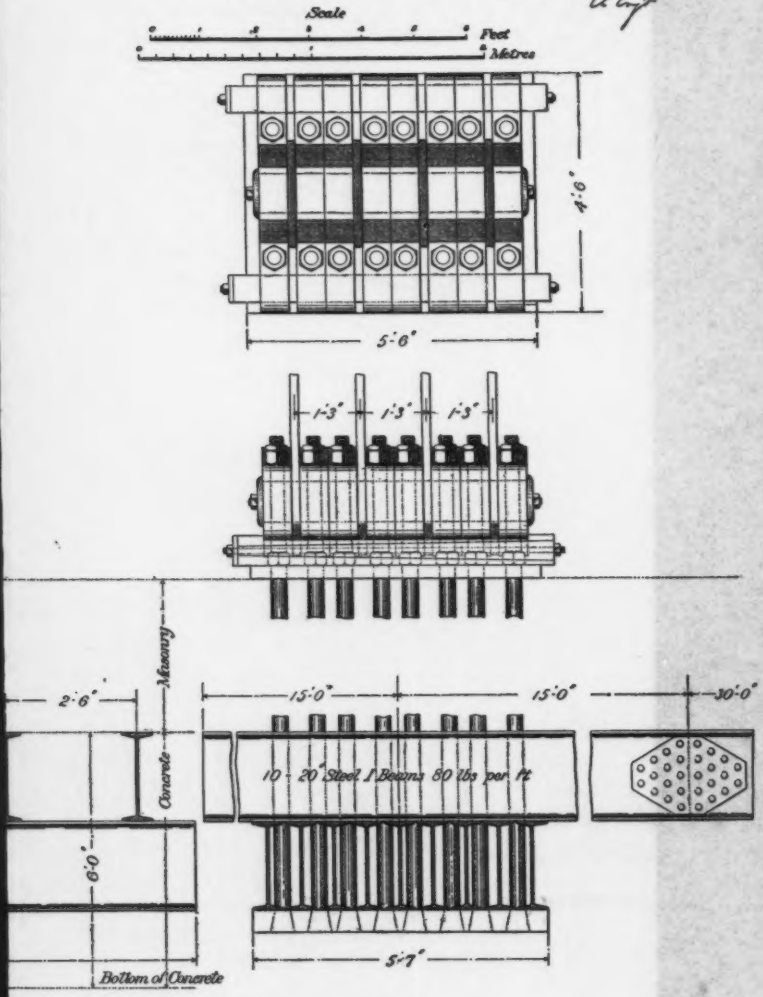

L8
2·10"
2 Web Plates 34"·⅜"
4 Angles 4"·4"·½"
4 Bars 10"·1"
4 Bars 10"·⅞"
1 Web Plate 39"·½"
4 Angles 5"·5"·⅝"
9" Pin
2 Web Plates 30"·½"
4 Angles 6"·4"·½"
2 Bars 3"·⅞"
3½" Pin
2·6"
2·0"
4 Bars 24"·⅞"
9" Pin
8 Steel Blocks 54"·6½"
Folding Wedges
2·5"
2·6"
2·1
1·8"
1·3"
10"
1·3"
1·8"
2·1"
2·6"
9 – 20" Steel I Beams 80 lbs. per ft.
18·0"
Masonry
Concrete
6·0"
Bottom of Conc

K.C.&M.R.&B.Co.

MEMPHIS BRIDGE

Anchorage Connection.

G. S. Morison
C.E.

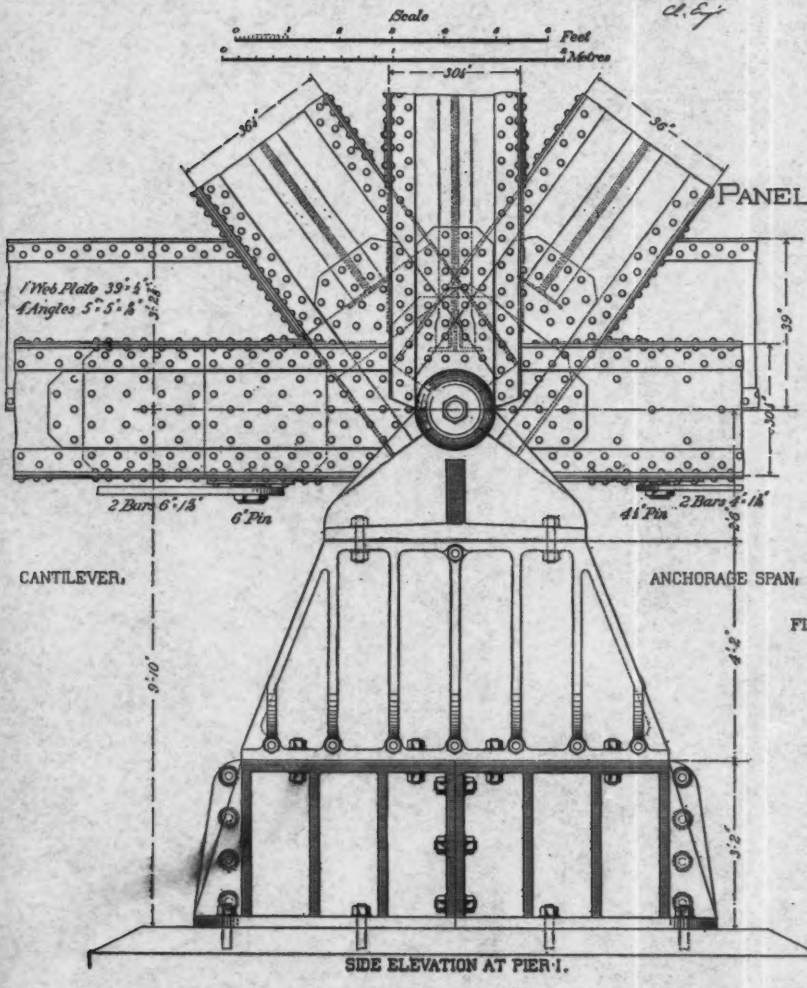


K.C.& M.R.& B.Co.

MEMPHIS BRIDGE.

Bearings, Piers I and III.

G. S. Morison
Ch. Eng.

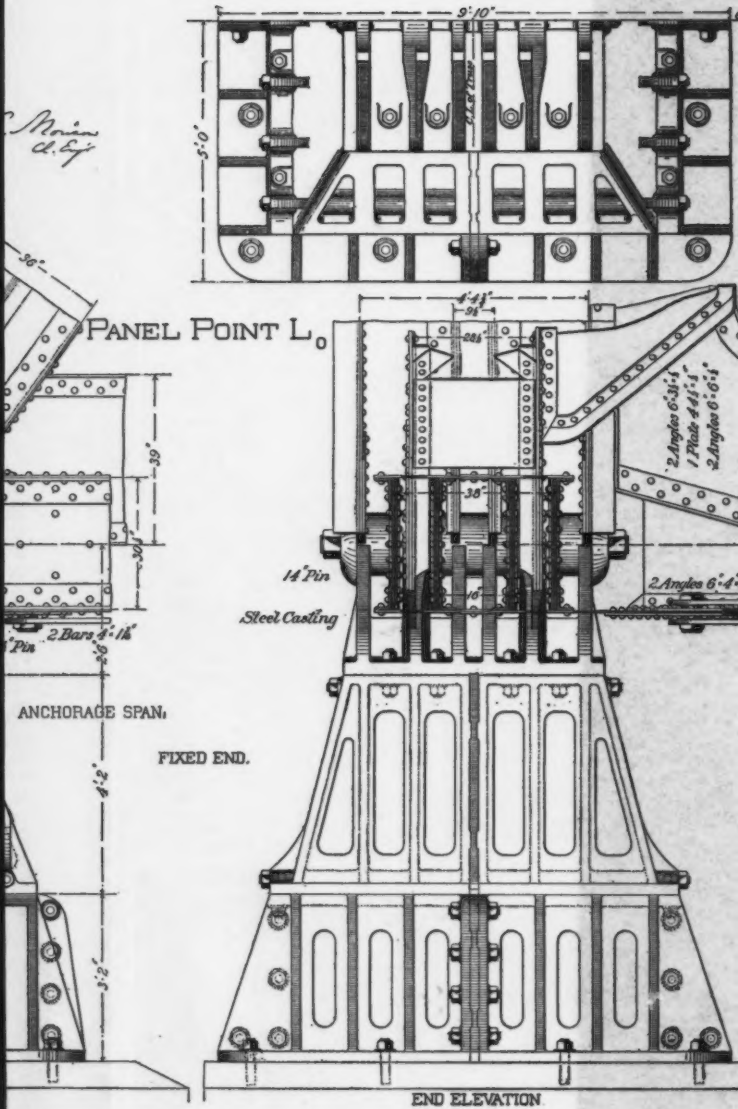


SIDE ELEVATION AT PIER I.

PANEL POINT L

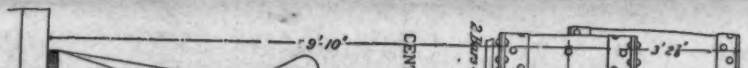
14

Steel Ca


PANEL POINT L_0
14" Pin
Steel Casting
2 Bars 4"×1⅛"
ANCHORAGE SPAN.
FIXED END.
END ELEVATION

624.
. ENGRS.
OF MEMPHIS BRIDGE.

HALF PLAN
OF
CASTINGS.

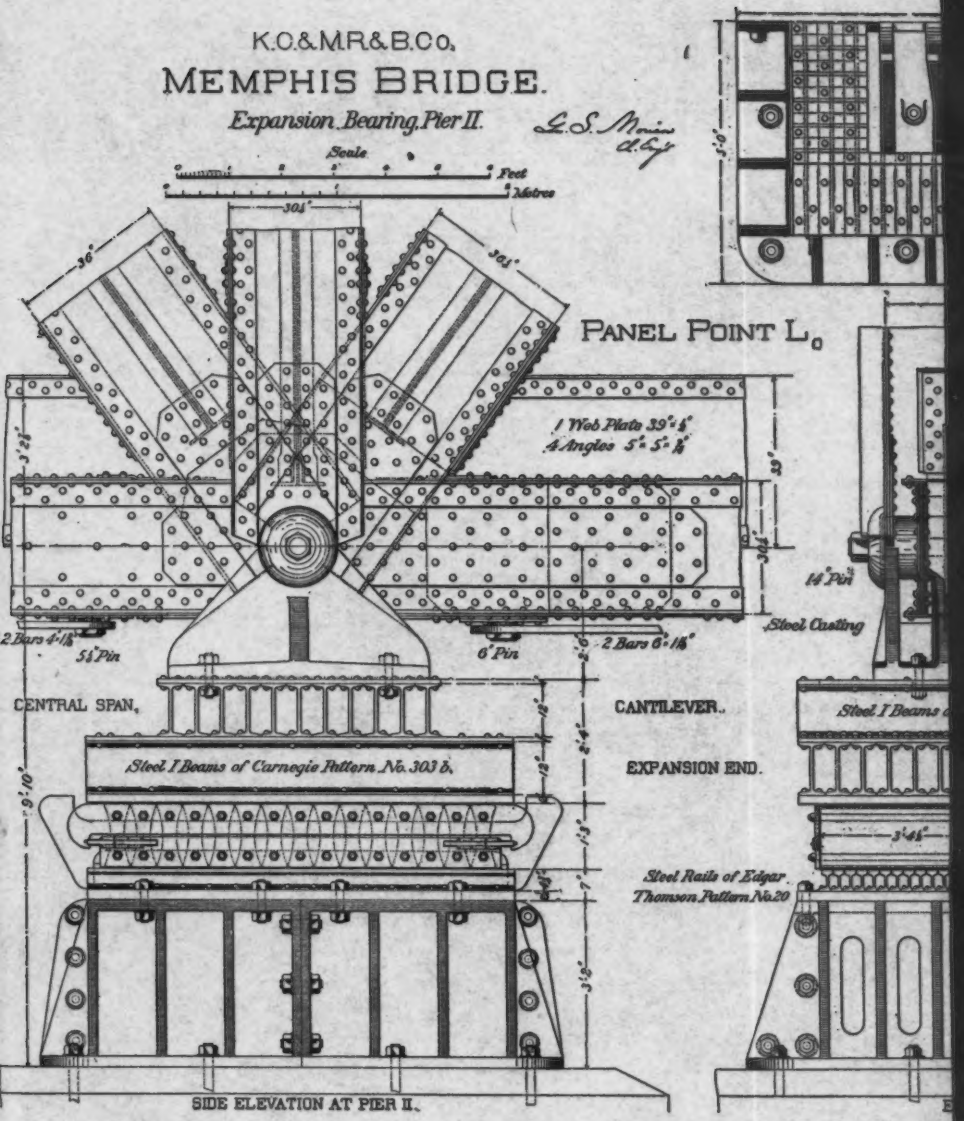

9'-10"
CENTRE
2"x6"
3'-2½"

K.C.&M.R.&B.Co.

MEMPHIS BRIDGE.

Expansion Bearing, Pier II.

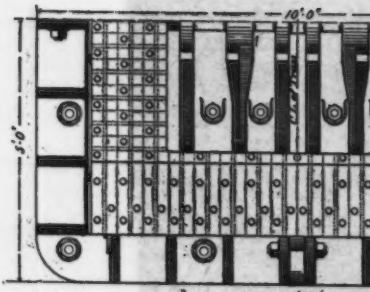
L. S. Moore
C. Engr



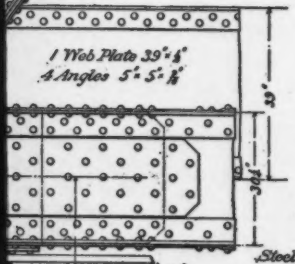
E.

L. S. Moir
A. Eng

Feet
Metres

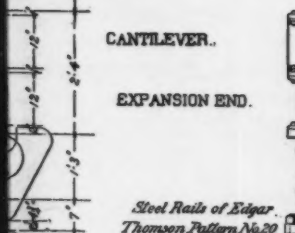


PANEL POINT L_0

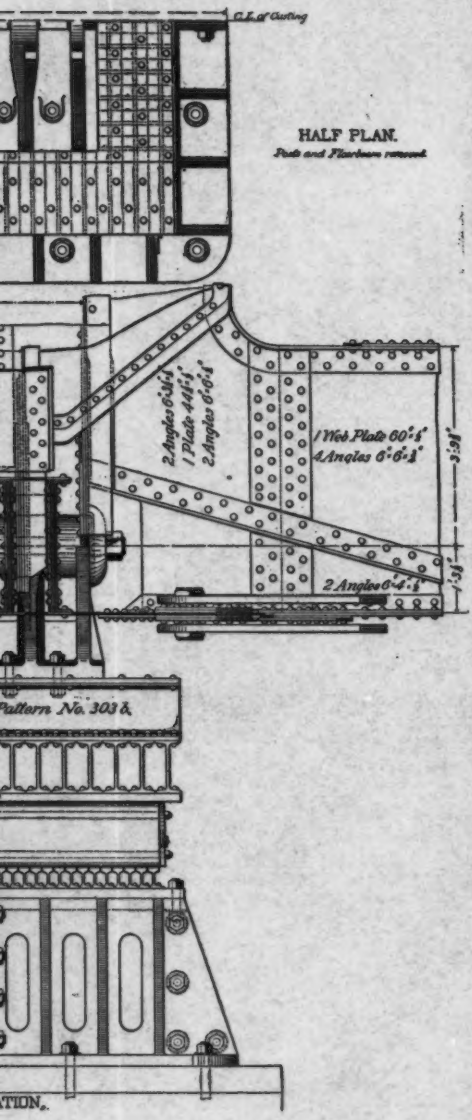


CANTILEVER.

EXPANSION END.



END ELEVATION.


C.L. of Casting
HALF PLAN.
Posts and Floorbeam removed
2 Angles 6"x4"x⅞"
1 Plate 44"x⅞"
2 Angles 6"x6"x⅞"
1 Web Plate 60"x⅞"
4 Angles 6"x6"x⅞"
2 Angles 6"x4"x⅞"
3'-9"
3'-3"
Pattern No. 303 S.

ATION.

K.C.&M.R.&B.Co.

MEMPHIS BRIDGE.

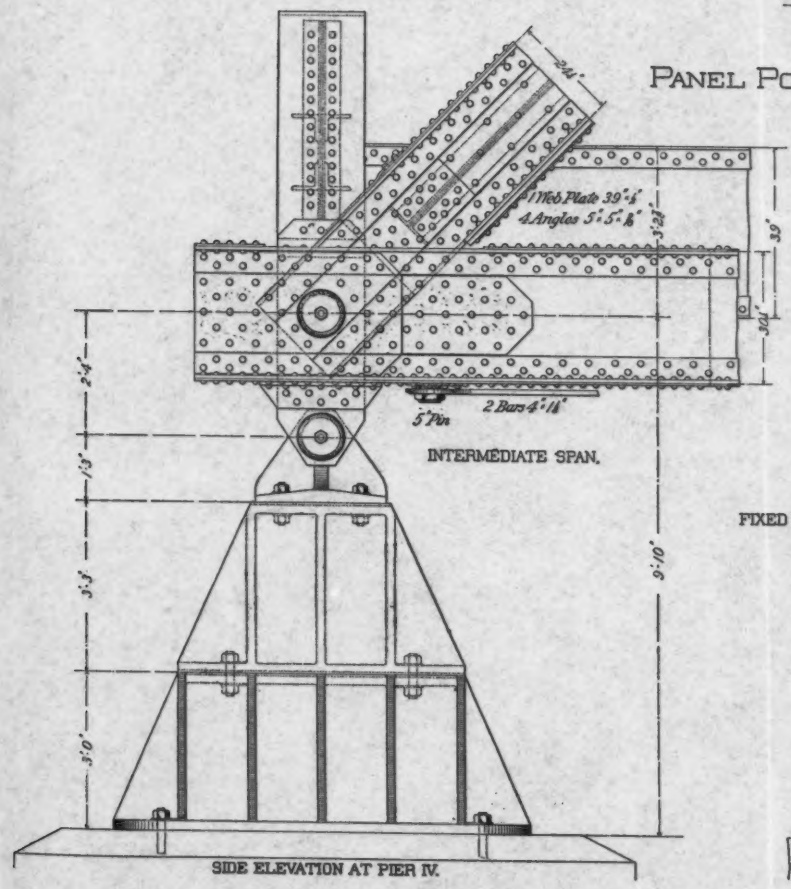
Bearing, Pier IV.

Scale.

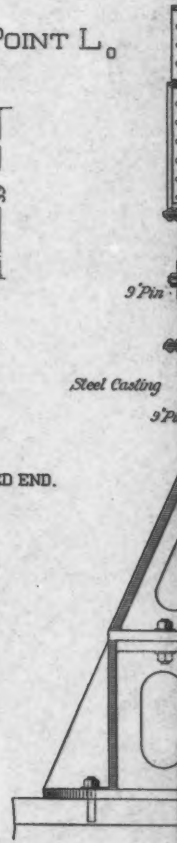
Feet

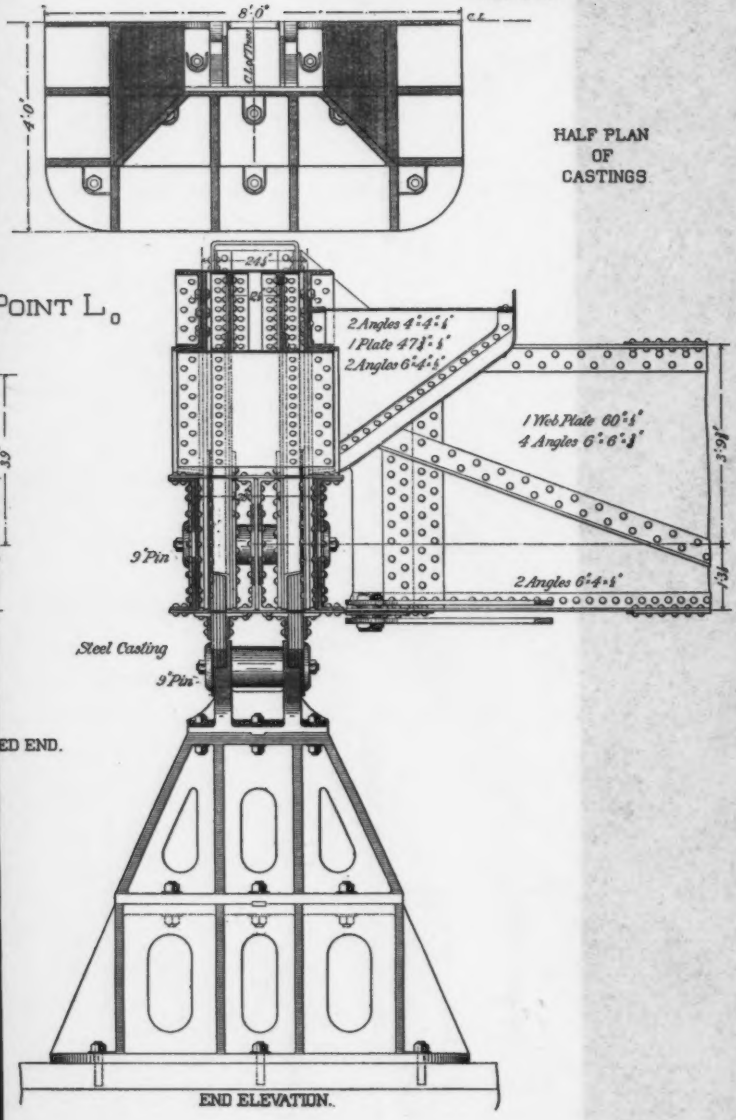
Metres

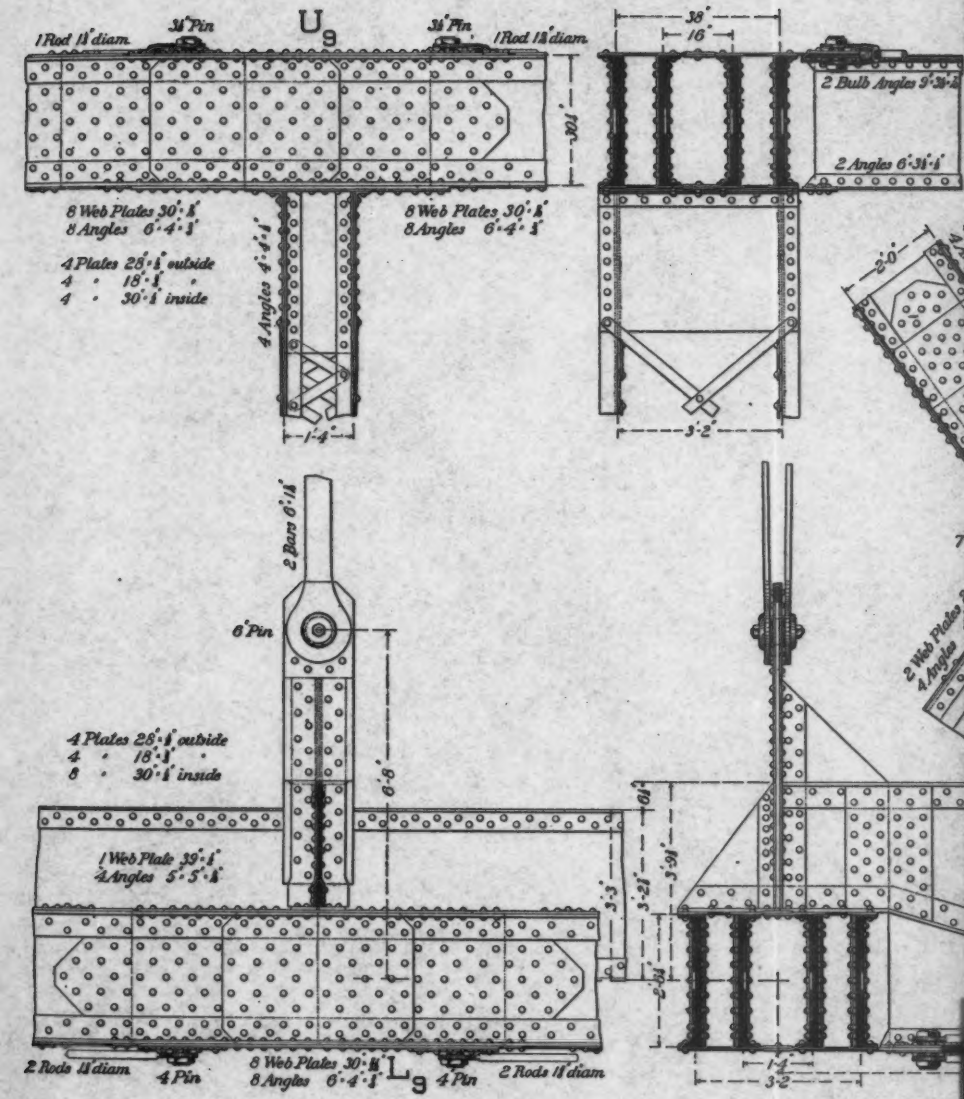
G. S. Morison
C.E.

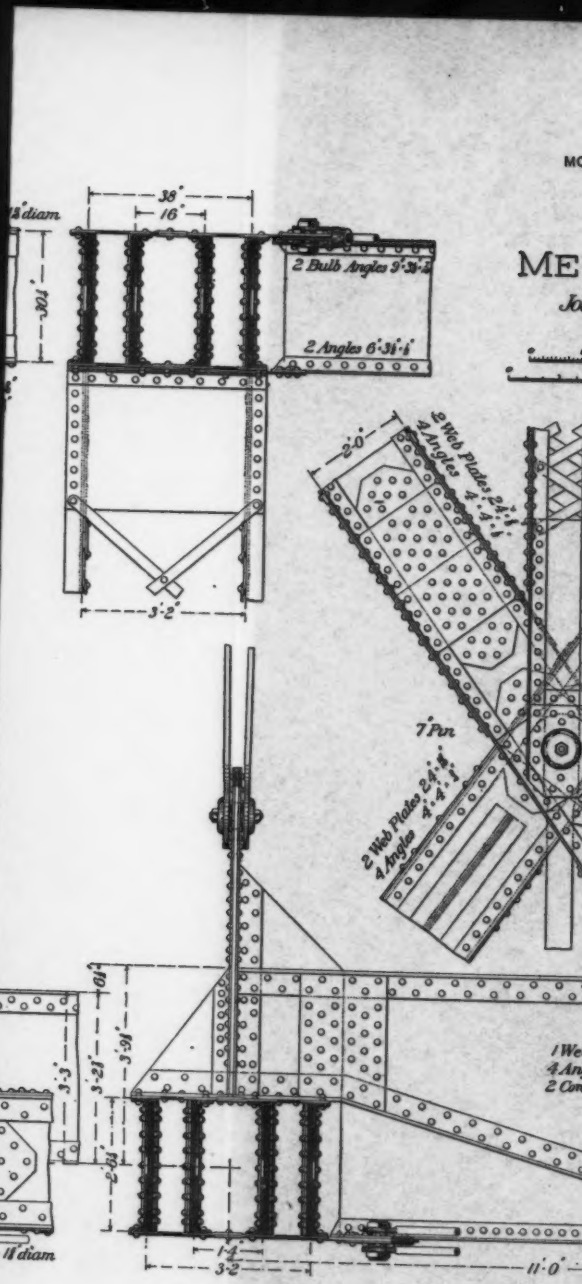


PANEL POINT L_0




8'-0"
c.l. Pins
4'-0"
HALF PLAN OF CASTINGS
24½"
POINT L₀
2 Angles 4"×4"×⅞"
1 Plate 47½"×⅝"
2 Angles 6"×4"×⅝"
1 Web Plate 60"×⅜"
4 Angles 6"×6"×⅞"
3'-9"
33"
9" Pin
2 Angles 6"×4"×⅝"
Steel Casting
9" Pin
ED END.
END ELEVATION.


U9
1 Rod 1¼ diam.
3½ Pin
3½ Pin
1 Rod 1¼ diam.
8 Web Plates 30·½
8 Angles 6·4·½
4 Plates 28·½ outside
4 · 18·½ ·
4 · 30·½ inside
4 Angles 4·4·½
1·4
8 Web Plates 30·½
8 Angles 6·4·½
38
16
2 Bulb Angles 9·2½·½
2 Angles 6·3½·½
3·2
2·0
2 Bars 6·½
6 Pin
6·6
4 Plates 28·½ outside
4 · 18·½ ·
8 · 30·½ inside
1 Web Plate 39·½
4 Angles 5·5·½
6½
3·9½
3·2½
3·3
2·3½
2 Rods 1¼ diam.
4 Pin
8 Web Plates 30·½
8 Angles 6·4·½
L9
4 Pin
2 Rods 1¼ diam.
1·4
3·2

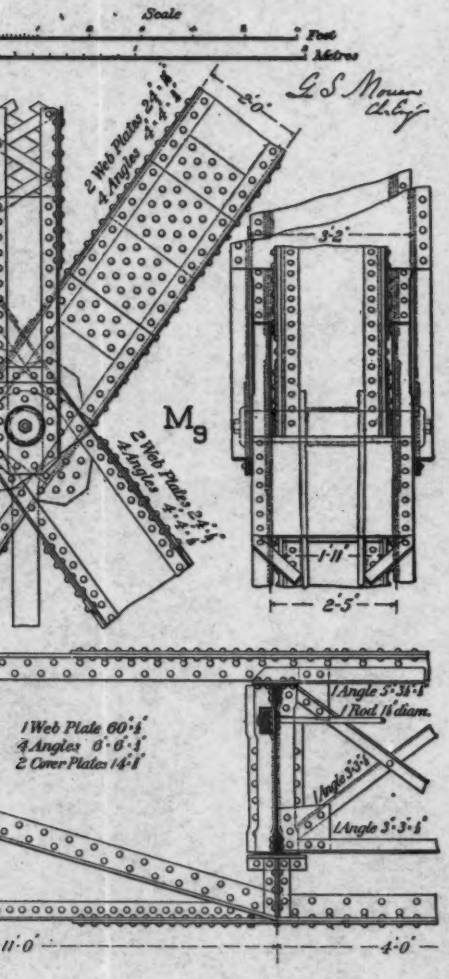

2 Bulb Angles 9"·3"·2
2 Angles 6"·3½"·½"
2 Web Plates 24"·½"
4 Angles 4"·4"·½"
7 Pin
2 Web Plates 24"·½"
4 Angles 4"·4"·½"
3·2"
11·0"

VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE X.

K.C.& M.R.& B.Co.

EMPHIS BRIDGE

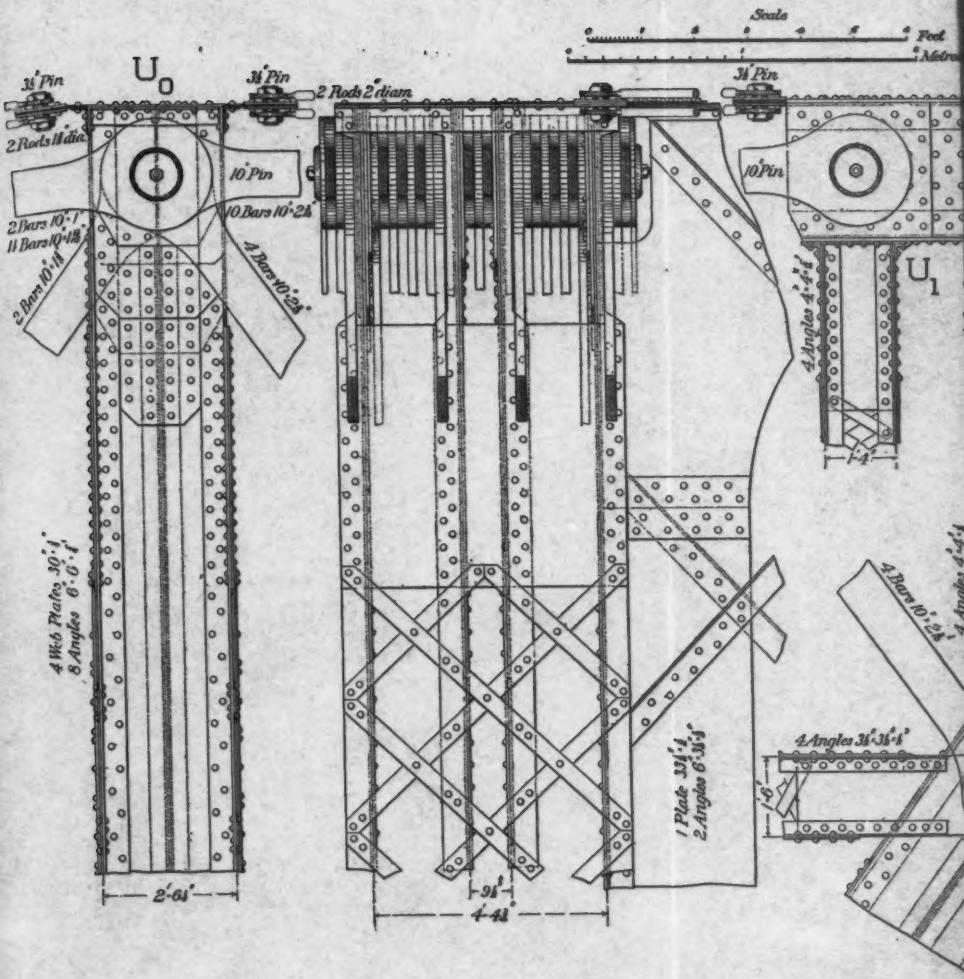
Joints in Chords, Central Span.



K.C.& M.R.& B.Co.

MEMPHIS BRIDGE

U_0 Panel Point, Central Span.

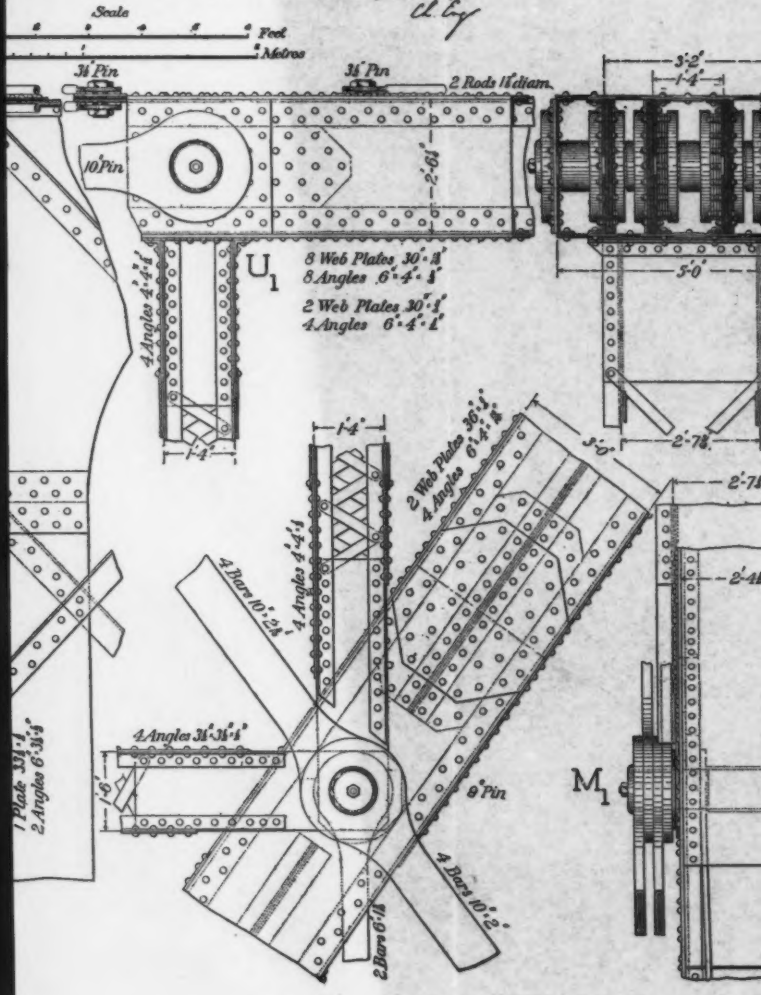


K.C.&M.R&B.Co.

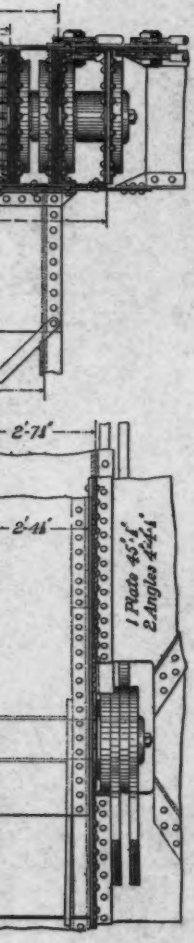
MPHIS BRIDGE

Panel Point, Central Span.

G. S. Morison
C.E.



No. 624.
C. CIV. ENGRS.
URE OF MEMPHIS BRIDGE.
E XI.



2 Bars 6'18"
3/Pin

K.C.& M.R.& B.Co.

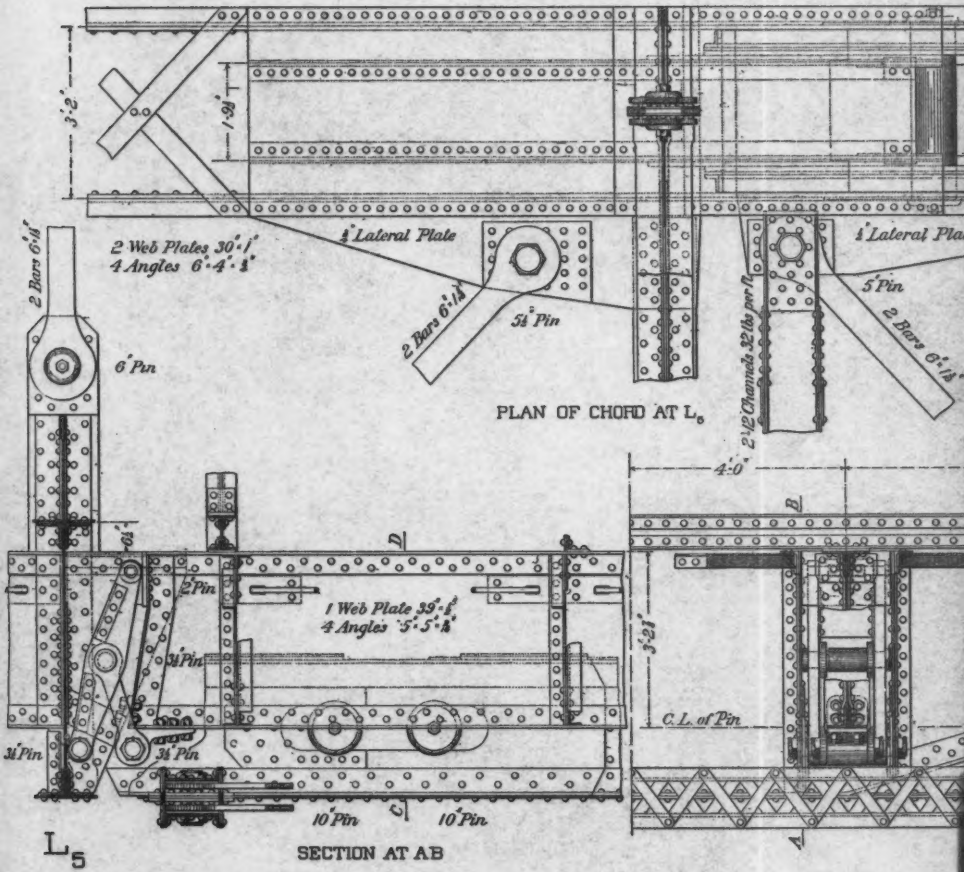
MEMPHIS BRIDGE

Expansion Joints: Lower Chord and Stringers, Interm

Scale

Feet

Metre



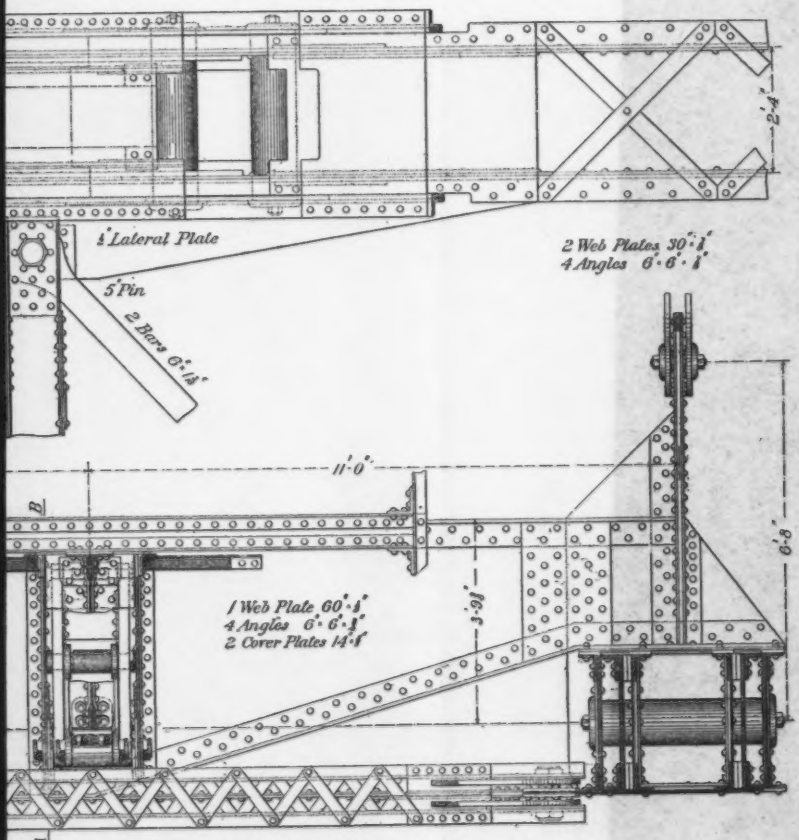
R.& B.Co.

S BRIDGE

nd Stringers, Intermediate Span.

ale
Feet
Metres

G. S. Morison
M. Cr



SECTION AT CD

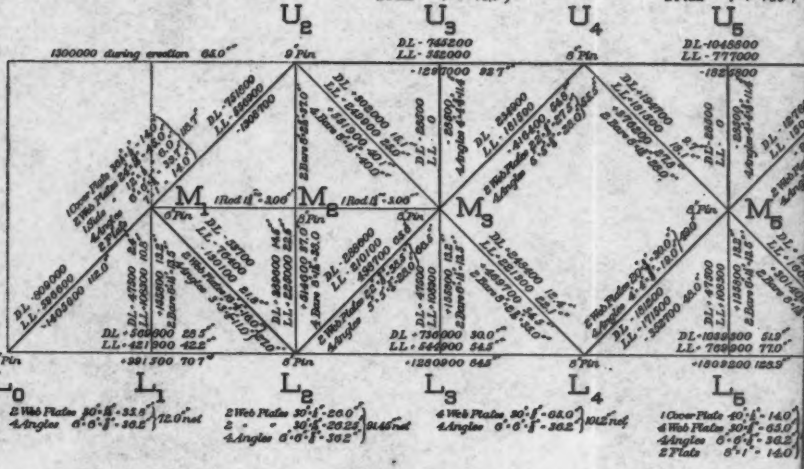
K.C.& M.R.& B.Co.

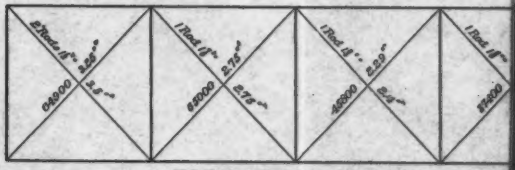
MEMPHIS BRIDGE

Strain Sheet. Intermediate Span.

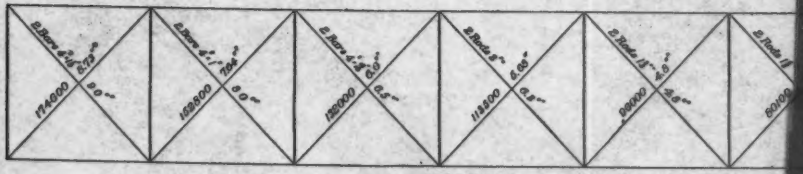
Intermediate Span 451'-8" C.to C. End Pins;
equal, sixteen (16) half panels of 28'-2½ each;
30'-0 C.to C. Trusses; 56'-4½ C to C Chords

Live Load 2000 lbs per foot per truss = 56500 lbs per half panel
" " 2700 " " " " " = 76273 " " " = 28500 at top
47715 " bottom.





TOP LATERAL SYSTEM.



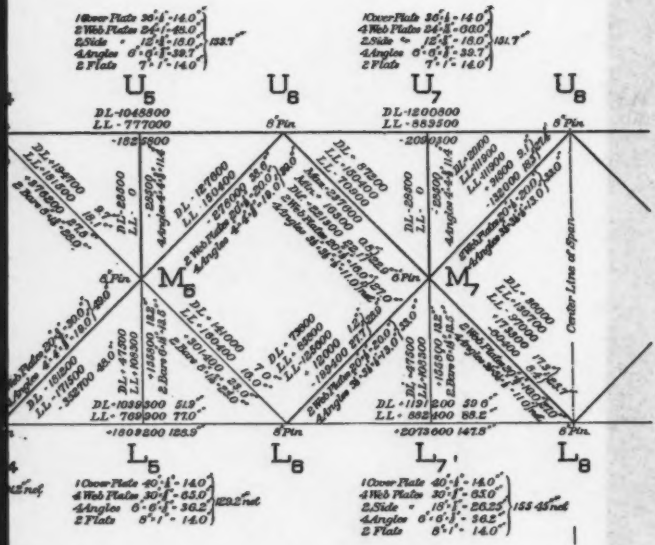
BOTTOM LATERAL SYSTEM.

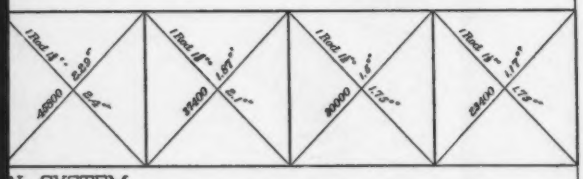
L.R.& B.Co.

S BRIDGE

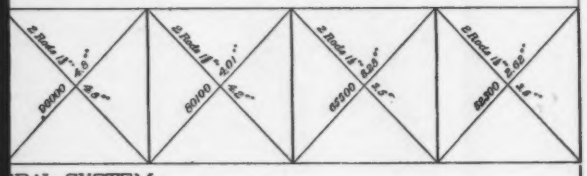
ntermediate Span.

G. S. Morison
M. Inst. C.E.





AL SYSTEM.



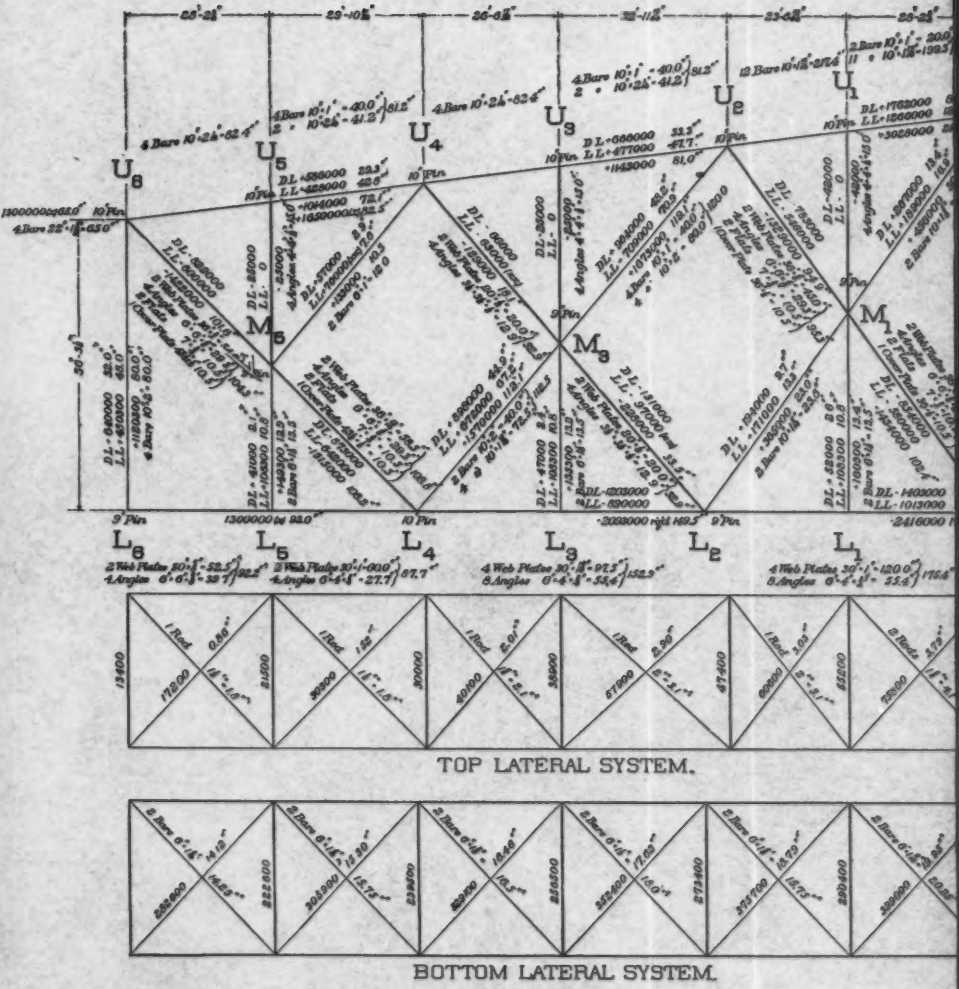
RAL SYSTEM.

Assumed Wind Pressure.
300 lbs per foot at top
600 " " " bottom

K.O.& M.R.& B.Oo.

MEMPHIS BRIDGE

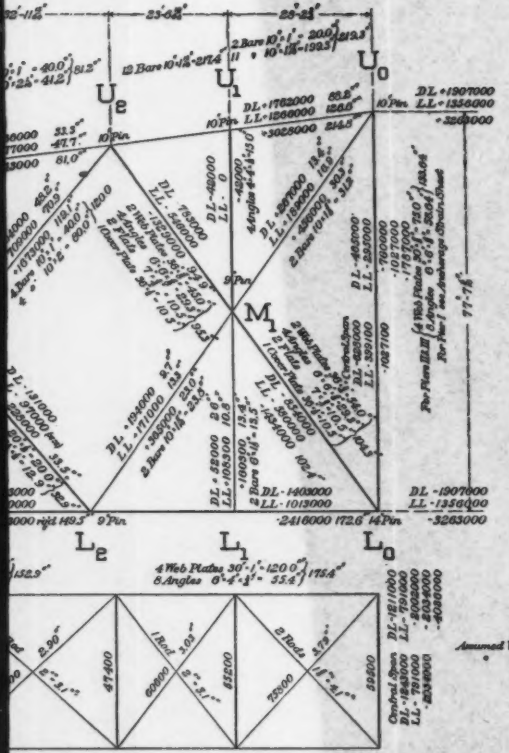
Strain Sheet, Cantilever Arm.



R & B.Oo.

BRIDGE

Cantilever Arm.


U2
U1
U0
M1
L2
L1
L0
DL +1907000
LL -1356000
-3263000
DL -1907000
LL -1356000
-3263000
DL -2416000 172.6
LL -1722000
-4138600
DL -1403000
LL -1013000
-2416000
DL -1403000
LL -1013000
-2416000
DL +1762000
LL -1266000
+3028000
DL -1762000
LL -1266000
-3028000
DL +1534000
LL +1102000
+2636000
DL -1534000
LL -1102000
-2636000
DL +1305000
LL +938000
+2243000
DL -1305000
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+275000
DL -160000
LL -115000
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DL +121000
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-208000
DL +82000
LL +59000
+141000
DL -82000
LL -59000
-141000
DL +43000
LL +31000
+74000
DL -43000
LL -31000
-74000
DL +4000
LL +3000
+7000
DL -4000
LL -3000
-7000
2 Bars 10'-1" - 200 lbs 212.3
2 Bars 10'-12" - 192.5
12 Bars 10'-12" - 217.4
4 Web Plates 30'-1" - 120.0" 175.4"
8 Angles 6"-4"-1" - 55.4
4 Web Plates 30'-1" - 120.0" 152.9"
8 Angles 6"-4"-1" - 55.4
4 Angles 4"-4"-1/2"
2 Bars 10"-1" - 40.0" 81.2"
2 Bars 10"-12" - 41.2"
4 Bars 10"-1" - 40.0" 118.1"
4 Bars 10"-12" - 66.0"
2 Web Plates 6'-0" - 3/4" 120.0
2 Bars 10"-12" - 82.5
2 Bars 10"-12" - 103.1
2 Bars 10"-12" - 123.7
2 Bars 10"-12" - 144.3
2 Bars 10"-12" - 164.9
2 Bars 10"-12" - 185.6
2 Bars 10"-12" - 206.2
2 Bars 10"-12" - 226.8
2 Bars 10"-12" - 247.4
2 Bars 10"-12" - 268.0
2 Bars 10"-12" - 288.6
2 Bars 10"-12" - 309.2
2 Bars 10"-12" - 329.8
2 Bars 10"-12" -

4.

ENGRS.

MEMPHIS BRIDGE.

Morrison
C. Engr

41" C. to C. End Pins;
panels of 25'-25"
-0" C. to C. of Trusses.

		U_0	31000
	25000	U_1	42000
		U_2	40000
	27000	U_3	23000
		U_4	17000
	12000	U_5	25000
		U_6	15000

Taken in Strain Sheet.

...ring erection
...of 100,000 applied at L_5

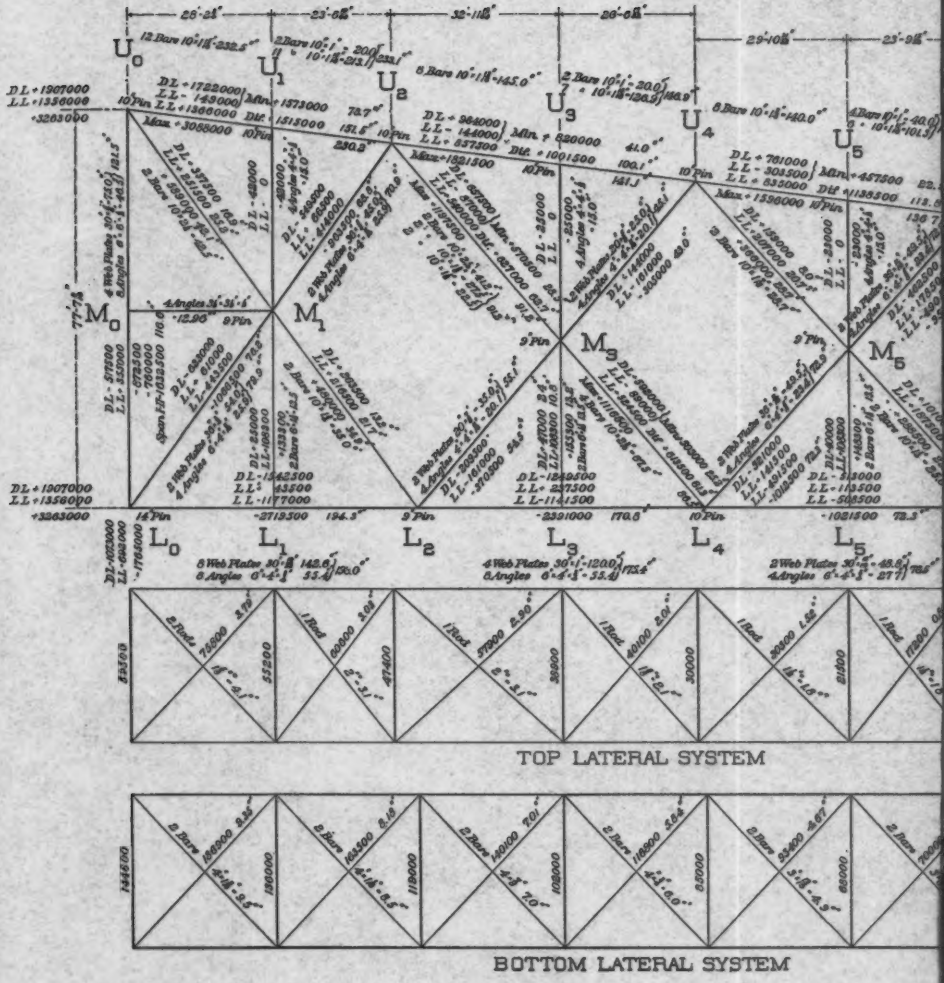
...d per Truss
...,500 lbs. per one half panel.

...per foot at top
... " " bottom.

K.O.& M.R.& B.Co.

MEMPHIS BRIDG

Strain Sheet, Anchorage Arm.

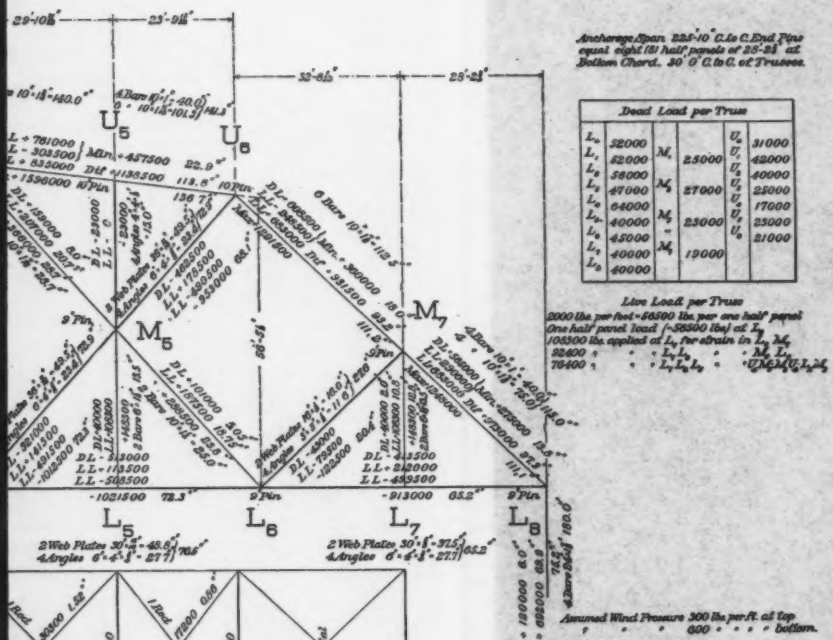


M.R.& B.Co.

IS BRIDGE

et, Anchorage Arm.

G. S. Morison
Ch. Eng'r

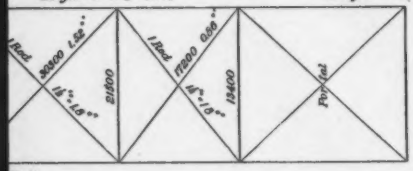


Anchorage Span 225'-10" C. to C. End Pins equal eight (8) half panels of 28'-2¼" at Bottom Chord. 30' 0" C. to C. of Trusses.

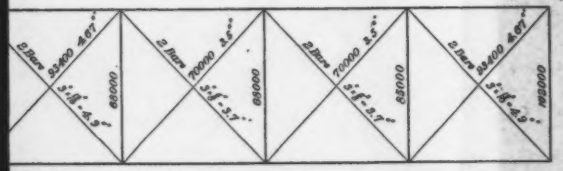
Dead Load per Truss					
L_0	32000	M_1	25000	U_0	31000
L_1	62000			U_1	42000
L_2	58000	M_3	27000	U_2	40000
L_3	47000			U_3	25000
L_4	64000	M_5	25000	U_4	17000
L_5	40000			U_5	23000
L_6	45000	M_7	19000	U_6	21000
L_7	40000				
L_8	40000				

Live Load per Truss
2000 lbs. per foot = 56500 lbs. per one half panel
One half panel load (=56500 lbs) at L_0
106300 lbs. applied at L_1 for strain in L_0 M_1
92400 " " " L_2 " " M_3 L_2
70400 " " " L_3 L_4 " " U_3 M_3 L_3 M_5

Assumed Wind Pressure 300 lbs per ft. at Top
" " 600 " " " bottom.



EM



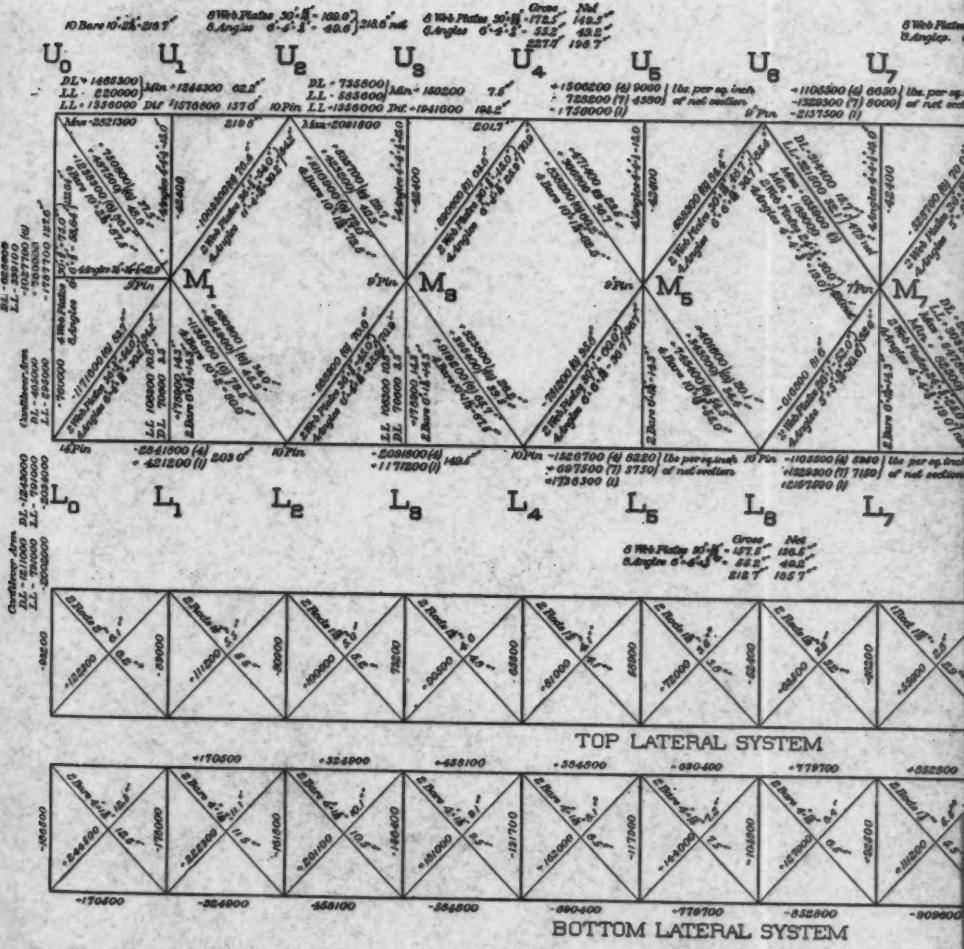
TEM

Cantilever Arm
D.L - 1211000
L.L - 791000
D.L -1243000
L.L - 791000
Cantilever Arm
D.L - 465000
D.L - 625000
L.L - 288100
=1027700 (s)
= 760000

K.O.&M.R.&B.Co

MEMPHIS BRIDGE

Strain Sheet, Central Span

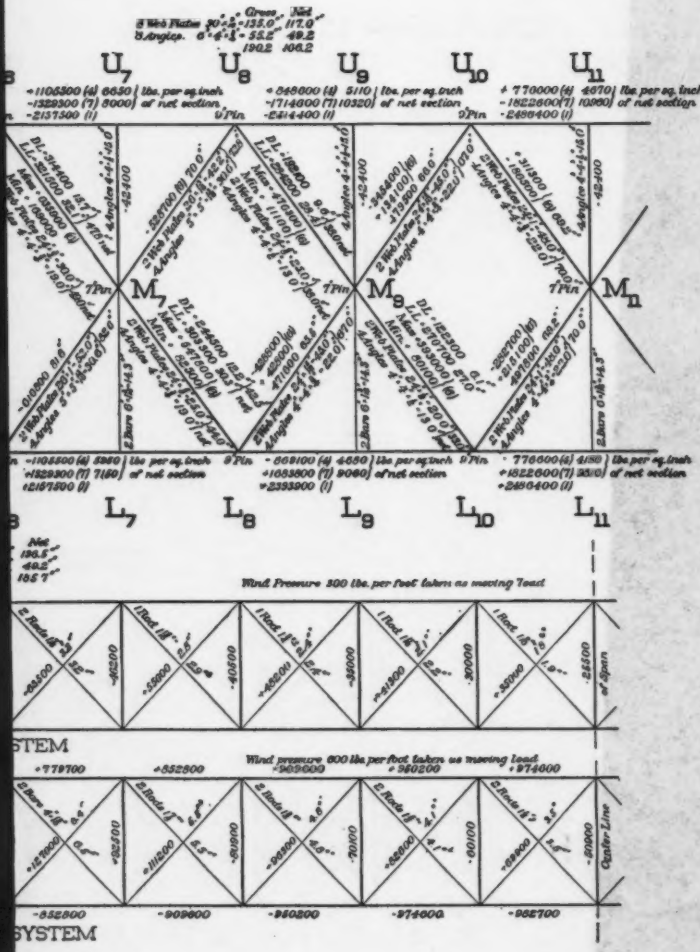


3.00

BRIDGE

ral Span

G S Morison
Cl Engr



K.C.&M.R.&B.Co.

MEMPHIS BRIDGE

Strain Sheet Details, Central Span.

Central Span. 621'-0" C. to C. End Pins, equal, to only five (5) half panels of 25'-2" each. 20'-0" C. to C. Transver. 77'-7½" C. to C. Chords

DL = 4000 lbs per foot per truss = 112000 lbs per l panel } 42400 lbs at top / 70600 " " bottom
LL = 2000 " " " " = 56500 " " l "
EL = 3000 " " " " = 84750 " " l "

Independent Span DL only

2nd. Central Span. DL - both side spans DL

3rd. Central Span. DL - one side DL other DL and LL

4th. Central Span. DL - both side spans DL and LL

Web members same as in 1st supposition

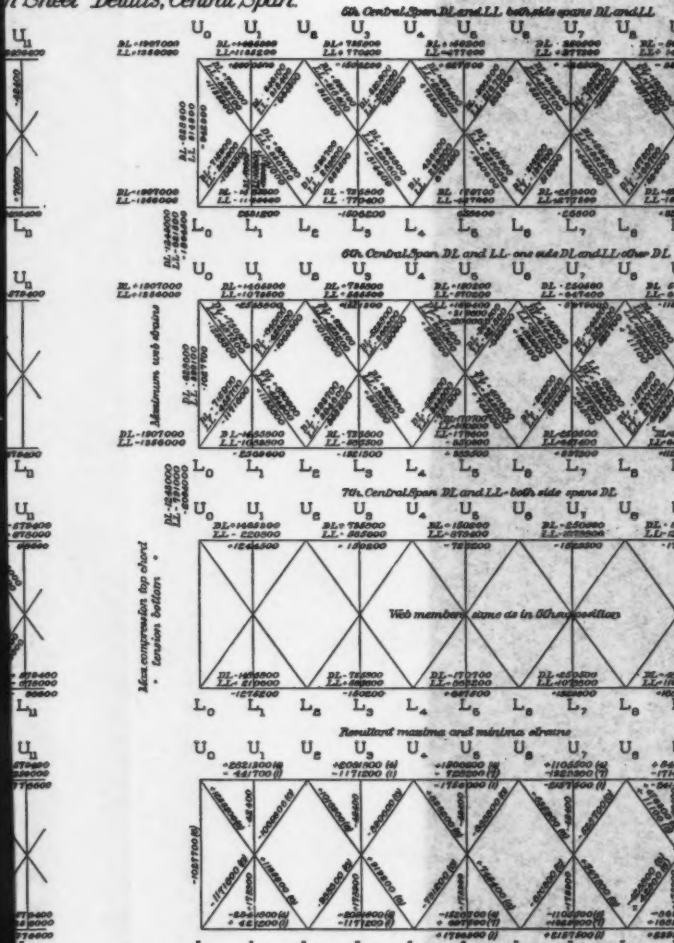
Max compression top chord
" tension bottom "

Maximum sub strains

K.C.&M.R.&B.Co.

MPHIS BRIDGE

n Sheet Details, Central Span.


6th. Central Span. DL and LL both side spans DL and LL
6th. Central Span. DL and LL one side DL and LL other DL
7th. Central Span. DL and LL both side spans DL
Web members same as in 6th span of diagram
Resultant maxima and minima strains
Max. compression top chord
Max. tension bottom
Maximum web strains

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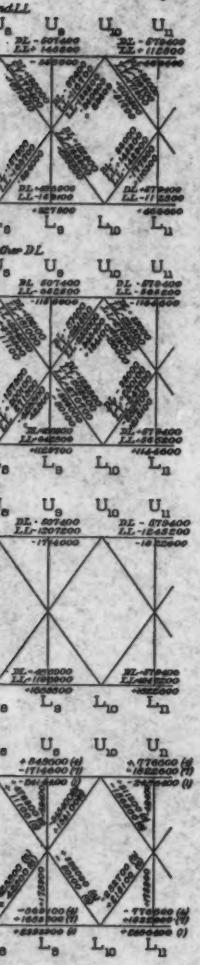
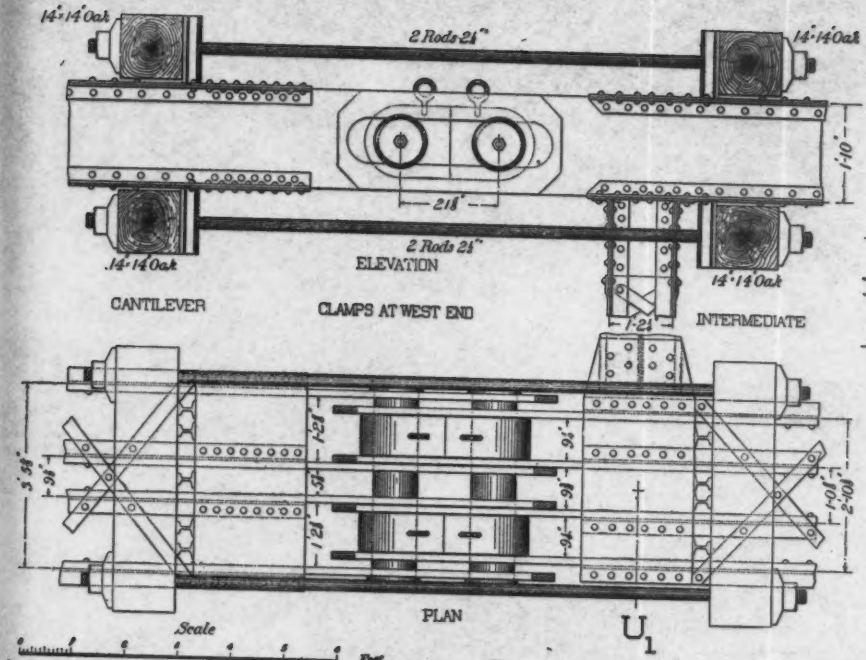
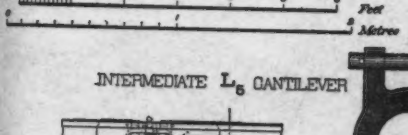
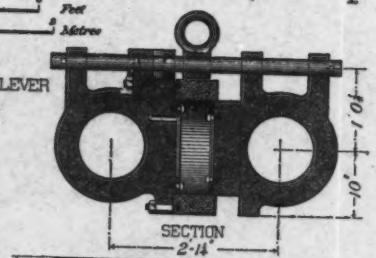
. CIV. ENGRS.
URE OF MEMPHIS BRIDGE.
XVII.

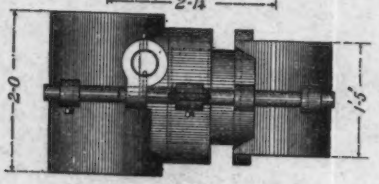
G S Morison
M Engr



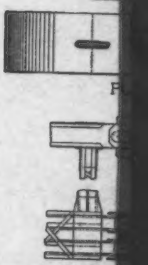








HYDRAULIC ADJUSTMENT AT EAST END



PUMP FOR HYDRAU

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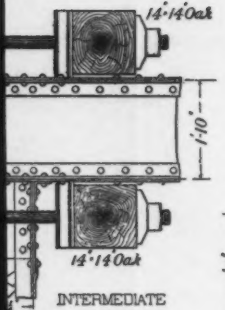
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XVIII.

K.C.&M.R.&B.Co.

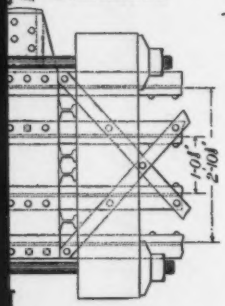
MEMPHIS BRIDGE

Adjustments at Ends, Intermediate Span.

G. S. Morison
Cl. Engr

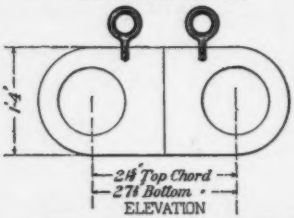


INTERMEDIATE

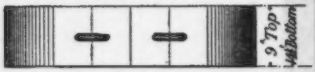


1

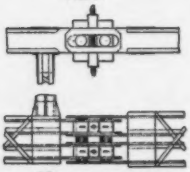
CASTINGS AT WEST END



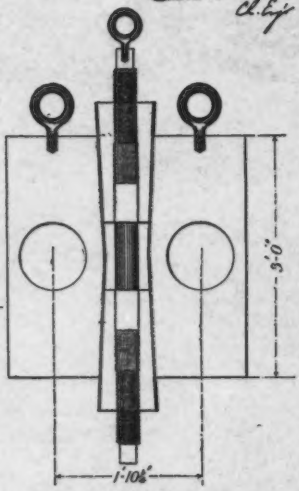
ELEVATION



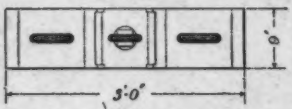
PLAN



INTERMEDIATE U_1 CANTILEVER

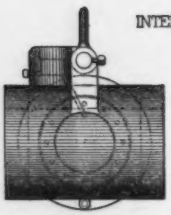


ELEVATION

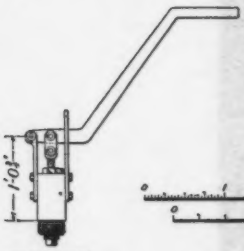


PLAN

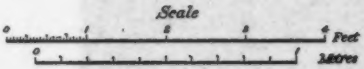
WEDGES AT EAST END

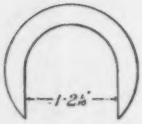


END ELEVATION

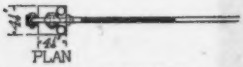


ELEVATION





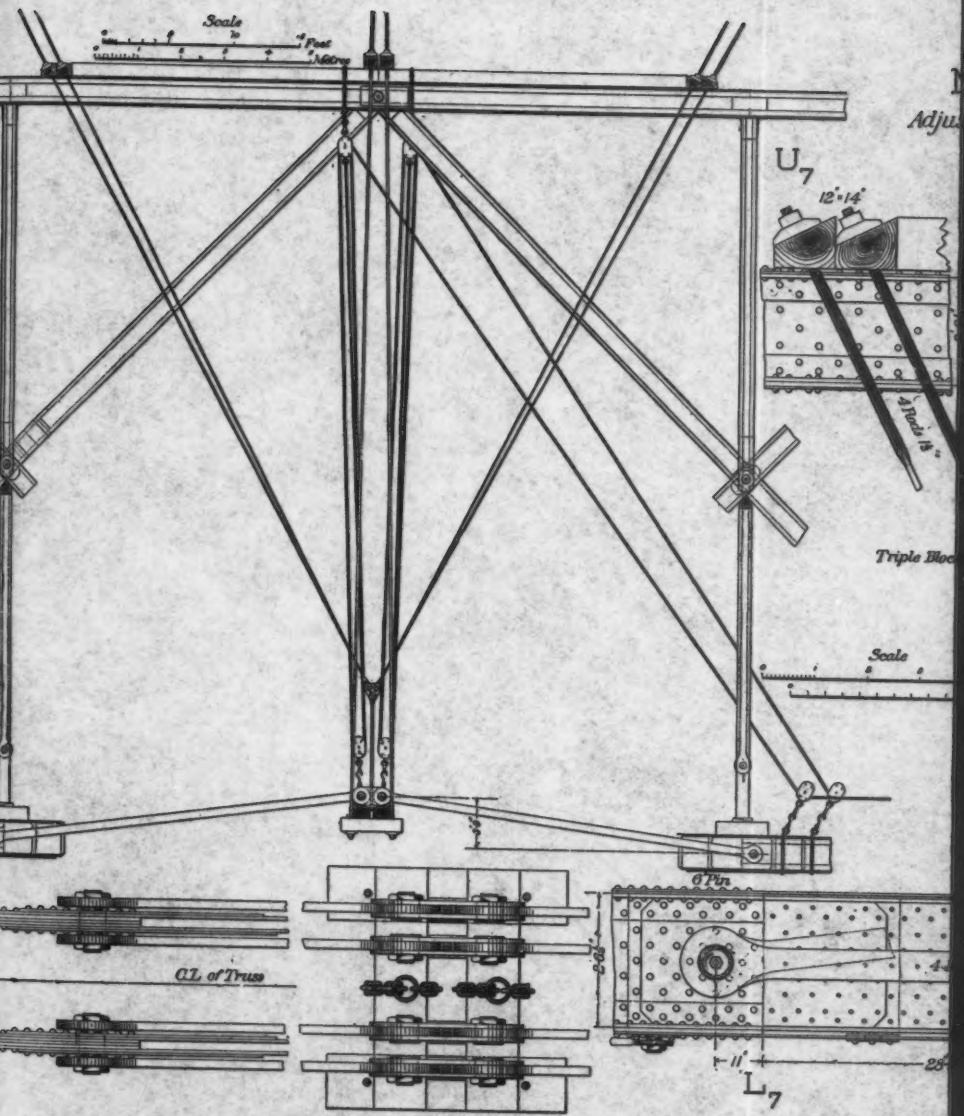
FILLER



PLAN

PUMP FOR HYDRAULIC ADJUSTMENT

AT EAST END


Scale
1 Foot
U7
12"×14"
4 Rods 1⅛"
Triple Bloc
Scale
6 Pin
CL of Truss
L7

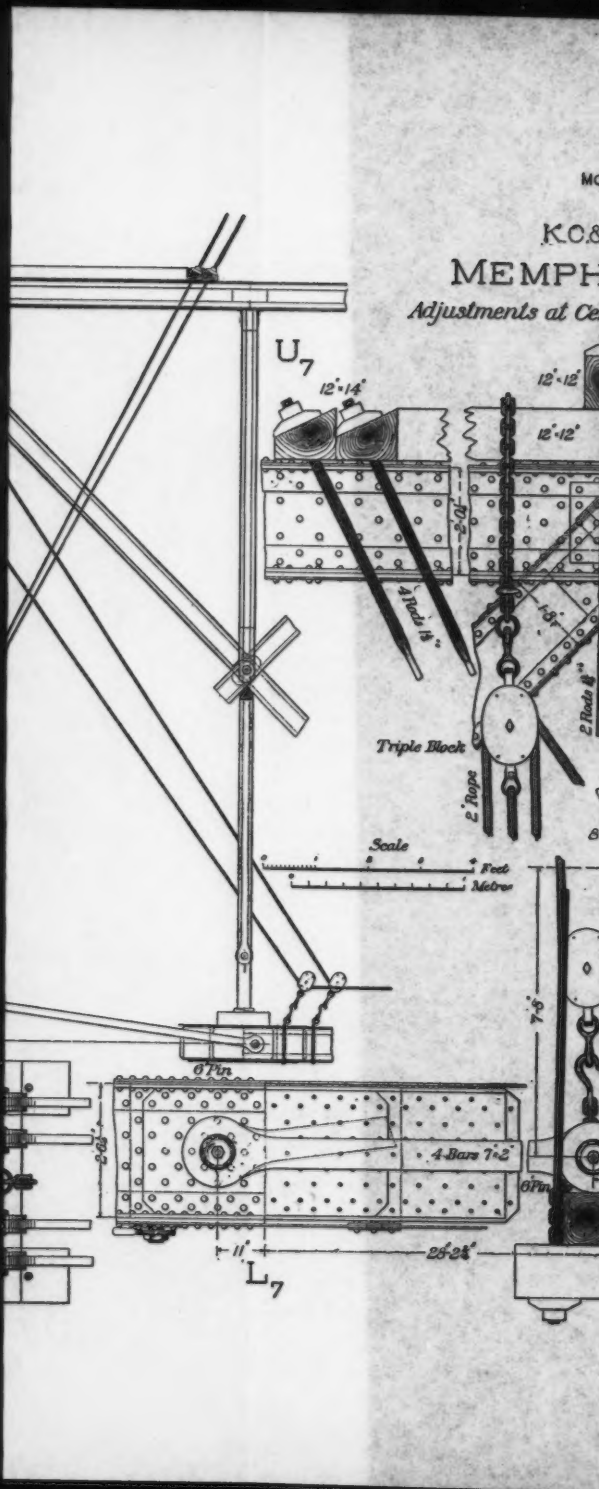

K.C.S
MEMPH
Adjustments at Ce
U7
12"·14"
12"·12"
12"·12"
24"
4 Rods 1⅛"
1·5"
2 Rods 1"
Triple Block
2 Ropes
Scale
Foot
Metre
7·5"
6" Pin
4 Bars 7"·2"
6" Pin
2·3"
11"
25·2⅛"
L7

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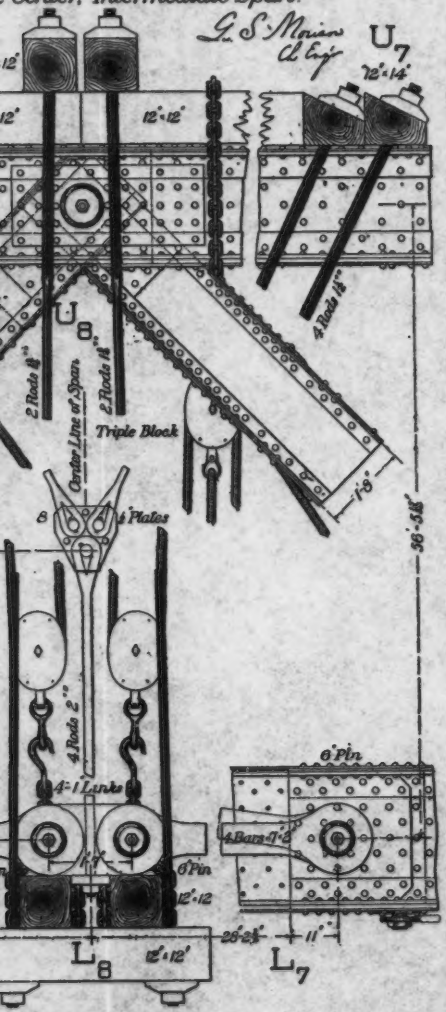
PLATE XIX.

C.& M.R.& B.Oo.

PHIS BRIDGE

t Center; Intermediate Span.



25. A full report of the laboratory tests shall be furnished, certified by an inspector, accepted by the Chief Engineer.

26. The broken and bent specimens shall be preserved subject to the orders of the Chief Engineer.

27. Notices shall be sent in duplicate to the Chief Engineer at his Chicago office, and to the shop inspector at the works.

28. Analyses shall be made by the manufacturer of every melt, showing amount of phosphorus, carbon, silicon and manganese, and certified copies of these analyses shall be furnished to the mill inspector, who will forward them to the Chief Engineer. The phosphorus and carbon analyses shall always be made. Analyses for silicon and manganese shall be made whenever called for by the inspector. Copies of all analyses, whether made by the request of the inspector or by the desire of the manufacturer, shall be furnished to the Chief Engineer.

29. Duplicate reports in full detail, including reports of chemical analyses, shall be sent to the Chief Engineer at his Chicago office, and also to the shop inspector at the works, not later than the day on which the accepted material is shipped.

30. Two notices of shipment of manufactured material, identifying the melts and dimensions, shall be mailed on the day after such shipments are made, one to be sent to the Chief Engineer at his Chicago office, and one to the shop inspector at the works.

31. Every finished plate, bar or angle shall be stamped on one side near the middle with a number identifying the melt, and this stamp shall be surrounded by a heavy circle of white paint. Steel for pins shall have the melt numbers stamped on the ends. Rivet and lacing steel and small pieces for pin plates and stiffeners may be shipped in bundles securely wired together with the melt number on a metal tag attached.

32. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds.

33. The cross-section shall never differ more than 2% from the ordered cross-sections as shown by the dimensions on the plans.

34. All sheared edges shall be planed off so that no rough or sheared surface shall ever be left on the metal.

35. Steel for pins more than 4 ins. in diameter shall be hammered steel, and tests shall be made on this steel in accordance with the requirements of Section 22. In such tests an elongation of 15%, and a reduction of area of 30%, given in each of two test bars tested separately, will be accepted as satisfactory, provided the character of the fracture is satisfactory. The bending test required in Section 20 shall be made on pin steel, but pin steel will not be rejected, provided the bar will bend around a circle of a diameter equal to twice the thickness of the bar without cracking. Steel for pins shall be sound and entirely free from piping. All pins in the main trusses shall be annealed before they are turned, and shall be drilled through the axes.

GEORGE S. MORISON,
Chief Engineer.

JANUARY 1ST, 1891.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

625.

(Vol. XXIX.—September, 1893.)

BRIDGE SUBSTRUCTURE AND FOUNDATIONS IN NOVA SCOTIA.

By MARTIN MURPHY, D. Sc., C. E.; M. Can. Soc. C. E.; Pres. N. S. Inst. Sc.; Provincial Government Engineer, Nova Scotia.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The subject of adopting concrete as a substitute for masonry in bridge work has approached such magnitude that the author cannot but be diffident of his power to treat it satisfactorily within the ordinary limits of a paper of this kind. After a few preliminary observations, he will confine his remarks to a notice of the employment of Portland cement concrete as a building material in works coming directly within the scope of his own supervision in the Province of Nova Scotia for the past 10 years, and to what may be considered cheap and effective methods for finding or providing foundations for such structures when under water.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

All that science, skill and experience can, with the progress of time, be expected to achieve in designing and erecting metallic structures to convey railways and public highways over every channel, passage and avenue encountered, is being effected. Yet it is no less obvious that the same degree of attention is not being bestowed on the substructure. And although the iron or steel superstructure may demand more careful thought and more practical application, the substructure is no less important to consider, as it is an ever-varying quantity, just as the heterogeneous texture or uniformity of the ground may happen to vary, or as the nature or stability of the foundation-bed may prove sufficiently solid to support the load it has to sustain.

Safety, durability and economy, coupled with uniformity of design, characterize the typical American bridge, viaduct or roof. The cost of any span will chiefly depend on its dimensions and weight and the place or position in which it is to be erected; competition has so equalized and reduced the cost to a minimum that a reliable estimate is easily obtainable when these conditions are understood and specified. Not so with regard to the economy of the substructure. It too frequently happens that less skill is employed, and hence more waste takes place. The foundations of piers and abutments are too often treated as if fully determinate without due examination; suitable materials within easy distance are occasionally ignored to follow some rigid rule or order of construction, when their employment in other forms might be made to fulfill all the conditions necessary for the erection of rigid, reliable and permanent supports.

The convenience of obtaining a firm and reliable base by the formation of a solid mass of concrete and the facility with which it is made have led to its almost universal adoption, and its expediency as a substitute for stone above ground has been much discussed. Until recently, there were but few good examples of concrete that could equal in value natural stone of the commonest kind. It is now very different, for the daily increasing knowledge which regulates its manufacture has reached a degree of excellence hitherto considered unattainable.

In 1883 concrete was first used by the author as a substitute for masonry in the construction of highway bridges in Nova Scotia, at first sparingly and with hesitation; but of late it has been used largely and with much confidence. Its use for the support of the superstructure

of iron bridges was prompted by necessity, because of the scarcity of materials suitable for ashlar masonry, the cost of transportation, the lack of skilled workmen, and the rapidity with which concrete structures could be erected with ordinary labor. It was not expected that this use of concrete would receive favorable public consideration and it did not. It was treated by the press and by the public as an expensive innovation.

It was alleged that in the climate of Nova Scotia it was an impracticable intrusion and would not suit its intended purpose; and although it could not be said to be a mere experiment, because it had been used so largely abroad, still it was generally commented upon with disfavor. Nevertheless, concrete piers have been erected in the most exposed positions, in the midst of strong currents, without any external protection, where they are exposed to heavy ice floes, to blows from timber rafts and in many instances to undermining by scour, with very favorable results. The climate of Nova Scotia, although not characterized by as wide a range of temperature as that of Quebec and Ontario, is more severe in its effects on masonry and concrete, owing to more rapid and frequent changes in meteorological conditions. In this fitful climate, we have a range of from 15° below to 90° above zero Fahr.; but such alternations have, so far, produced no visible damaging effect; violent blows strike more impotently upon concrete than upon masonry, and it is not so liable to fragmentary slips or segregations because of its monolithic character.

In a paper read by the author before the Canadian Society of Civil Engineers in February, 1888, on "Concrete as a Substitute for Masonry in Bridge Work," and in the observations made thereon, the subject was fully discussed by him and by other members of the society, some of whom were personally acquainted with the work during the progress of construction as well as with its subsequent behavior. It is not the purpose of the author to repeat that discussion here; he may, however, be permitted to refer to it and to offer some supplementary remarks on the results of five years' further experience and on the manner in which concrete work, above ground, then introduced to the notice of the Canadian Society, is standing the test of time.

There have been 147 highway bridges of metal superstructure, resting upon abutments and piers of concrete, built in Nova Scotia within the last 10 years. Forty-four of these have been in existence for a

period of five years; some of them within the influence of the augmented and turbulent tides of the Bay of Fundy, most of them exposed to heavy drift ice and all of them to the extremes of climatic exposure, yet but one failure can be recorded, and that is, no doubt, owing to careless workmanship. The introduction of concrete as a substitute for masonry above the surface in Nova Scotia, has been attended with such results that its employment is being extended and adopted for the renewal of piers of railway bridges, piers that have been so abraded and displaced by clumps of moving ice that renewal in the interests of safety became imperative. There are two 150-ft. iron spans carrying the trains of the Windsor and Annapolis Railway over the Gaspereaux River, resting upon abutments and piers of concrete, recently erected. The piers of the Avon Bridge, on the same line of railway, have been encased by a matrix of concrete, to preserve the ashlar masonry from total destruction. This bridge was supported by eight piers and two abutments of freestone; it consists of nine spans of iron lattice truss, six of which are 160 ft. each, the other three being smaller. Neap tides rise about 24 ft., springs 4 or 5 ft. higher. The bridge was erected in 1879 and had for 10 years been a source of annoyance and expense to the railway company. The water penetrated the body of the masonry during high tide, and not being able to escape as fast as the tide receded, the severe frost operating upon it, through thaw and frost and frost and thaw, lent at every successive reflux its expansive influence to the tottering face stones, forcing them outwards little by little, until the whole mass became so unstable as to necessitate immediate renewal. An envelope of concrete within a timber framework proved a cheap and effective remedy; it has for the last four years withstood all such recurrent vicissitudes, and its present appearance give assurance of future permanency.

The adoption of the various building materials which Nature affords for the purposes of construction requires both practical and technical knowledge. When stone of a suitable nature for building can be had within reasonable distance or at moderate cost, we still prefer it; but where such conditions are absent we may be justified in copying Nature in rock-making and substituting manufactured monoliths in its stead. Concretes will differ in quality according to the care bestowed on the selection of the materials used and the methods by which they are compounded, and until it becomes a specialty

such work can only be satisfactorily done under the eye of the trained engineer.

The plates accompanying this paper give a typical illustration of concrete structures in existence and of works now being erected in Nova Scotia. The following extract is from the author's paper, pp. 81–82, Vol. I, *Transactions Canadian Society of Civil Engineers.*

"The abutments and piers were built within a skeleton framework closely boarded against the face as the work proceeded upwards. They were built of Portland cement rubble concrete, faced with Portland cement fine concrete. The facing of fine concrete was generally 6 ins. in thickness, but varied to a width of 9 ins. in rapid currents, or where liable to more severe usage than is due to ordinary exposure. The Portland cement rubble concrete was composed of 1 part of clean gravel or small stones not exceeding 1 in. in diameter, 5 parts of large stones weighing 20 lbs. and upwards, 2 parts of sand and 1 part of Portland cement. In mixing the concrete, the gravel, sand and cement were turned over three times while dry; water was then added and the materials again turned over at least three times and well agglomerated before being placed in the work. The gravel, sand and Portland cement for the fine concrete were first mixed, to form a matrix or body of concrete, and the large stones of the rubble concrete were placed therein by hand. These stones were placed end upwards, 2 to 3 ins. apart, and the spaces between them grouted up solid with the matrix, to form a compact mass, and any holes or cavities in the works run full flush with Portland cement compo, consisting of 2 parts of sand and 1 of cement. The fine concrete facing was kept at least 6 ins. higher than the rubble concrete, and united with it so as to form one homogeneous mass. In every instance the top of the pier was finished with fine concrete for a depth of 1 ft. 6 ins., and the shoes of the iron truss posts were placed thereon without the usual bridge seats of stone.

"The concrete work for the last three years (now for the last eight years) has been executed by the Government's own engineers and workmen." * * * "It was considerd more advisable to carry out the work by men working by the day and trained under proper supervision, until they became sufficiently skillful, and as interested as the engineer in the success of the undertaking."

Objections are frequently taken against the use of large stones within the concrete body, because homogeneity is said to be an essential feature to obtain the best results. The assumption that the bond between the large stones and the concrete is not so great as in the concrete itself is not an established one. Although tests by compression on small concrete columns give varying results, according to the kind of stone

and other materials used, it is not difficult to observe that the planes of cleavage are in the concrete itself, and the results compared with those of similar tests on similar kinds of stone broken to the size of Macadam are not at all so much in favor of the smaller intermixture as would warrant the exclusion of the large stones. The desirability of the employment of large stones in an economical sense will be determined by the supply available. In Nova Scotia they too frequently encumber the ground. Their adoption lessens the price of concrete more than 30 per cent. Ten 400-lb. barrels of Portland cement will build, on an average, 8 to 9 cu. yds. of concrete, and all the intervening intermixture of concrete will be rich in cement. The cost of concrete work in Nova Scotia has been from $5.50 to $6.50 per cubic yard for piers and abutments, and from $7 to $8 for concrete work in arched bridges.

The concrete work forming the arches of the small highway bridges shown by illustration was first built in courses radiating in the same manner as dressed stone in courses for arch work, so as to prevent any horizontal tendency to set flaky as the work went on. Each course was molded on the lagging of centers by securing thereon a board in the true radial line between soffit and extrados, and the concrete was placed there in its final position to form the course. When sufficiently set, the board was removed and placed again for the next succeeding course. A setting templet, the same as masons make use of when laying voussoirs or arch stones on centers, readily gave the inclination of the board. The foreman in charge was cautioned not to permit any course to be partially filled up and allowed to set before the whole was completed. In this way the course was expected to have the same consistency throughout. The concrete used in the arches was of the same admixture as described in this paper as "fine concrete." Recently, however, the arch work was built *en masse*, an ample supply of material being first produced, and the work, once commenced, was proceeded with as rapidly as possible to completion.

Generally speaking, suitable materials for the aggregates are to be found throughout Nova Scotia in a naturally fit condition for concrete-making, without preliminary treatment, except occasional washing. River and seashore gravels and sands from the denudation of granite, quartzite or whinstone rock from Cambro silurian strata are quite common, while clean pit gravels from old river-beds or from moraines are frequently available further inland. In all cases care was taken

that the aggregates were not used unless clean, free from earth or loam and from all organic substances. Nearly all the cement used was of "White's brand" of English Portland. It was always tested for tensile strength, weight, fineness and hydraulicity.

That no rigid rule or uniform order of construction of bridge substructure ought to be invariably followed when forces of conflicting elements have to be dealt with is well exemplified by the failures of structures erected over the rivers within the tidal influence of the Bay of Fundy. The author is not aware of any one instance where an ashlar masonry structure under such conditions of tidal influence has not been more or less a failure. The railway bridge crossing the Avon River at Windsor, already noticed, is not the only instance. The same remarks might be applied to piers or bridges carrying the Intercolonial Railway over the Shubenacadie and Sackville rivers, all of which have had to be renewed since their erection; while within the limits of those phenomenal fluctuations, characteristic of the Bay of Fundy, concrete made from aggregates obtained from off the shingle beaches close at hand has, so far as it has yet been properly employed, given satisfaction.

In the paper submitted to the Canadian Society in 1888, already alluded to, the history, theory and manufacture of Portland or artificial cement, and its application to bind the usual aggregates into concrete *en bloc*, was more fully noticed and discussed. The purpose here is to point out how it is behaving as a substitute for masonry in the climate of Nova Scotia. But, it may be asked, what is the justification for the employment of concrete at all above ground in lieu of stone? The fact that walls and bridges are produced which perform the service expected of them at a much less expense than masonry; that by the utilization of materials otherwise valueless, such as the shingle of the beaches and streams, and the boulders encumbering the surface, permanent bridges can readily be built with the assistance of ordinary labor; that by the employment of concrete, limited means will yield more desirable results; that evidence exists that such adoption would secure at low cost works of great efficiency, is sufficient to justify the use of concrete as well as the introduction of the subject of its adoption here.

Concrete work should not be proceeded with during the extremes of hot or of cold weather, without protection from such extremes. An

even temperature of about 60° Fahr. is the most desirable for its manufacture and use. During summer heat in our Canadian climate, the walls should be covered immediately after the introduction of the concreting material, and occasionally sprinkled over with a hose or through a finely punctured nozzle of a watering-can. Injurious effects from freezing are still more to be avoided. It is better to desist from concrete building early in the month of October. It is requisite that the concretionary process should go on with extreme slowness on the outer or exposed surface of concrete walls. The interior of the mass will set slowly; the induration should extend equally slowly in all directions so that the solidifying condition may be simultaneously reached throughout the body, and that the cohesive attraction and crystallization may be uniformly progressive.

Foundations.

The general principles of dealing with foundations where water offers no impediment to the execution of the work will not be noticed here. The remarks submitted will be confined to the methods devised and the practice employed in providing firm and reliable footings upon which to rest abutments, piers and cylinders, that support metal superstructure of railway and highway bridges built under the supervision of the writer. They may be classified thus:

First.—For cylinders, to rest on a friable rock river-bed, as at Avon Bridge, Windsor.

Second.—For cylinders founded on rock partially covered by shifting sand, as at Board Landing Bridge, Truro.

Third.—For cylinders to rest on a hard boulder, clay bottom, intermixed with large boulders, as at Bridgewater Bridge.

Fourth.—On soft alluvial bottom, as at Lockeport Bridge, Lockeport.

Fifth.—On soft clay bottom, foundation for circular swing pier, as at Little Bras d'Or Bridge, Cape Breton.

Sixth.—On piles cut 20 ft. under water for foundations of cylinders, as at Victoria Bridge, Bear River.

Seventh.—Within caissons to rest upon piling, as at Sutherland's River Bridge, Eastern Extension Railway.

Eighth.—With coffer-dam where water is excluded, as at Restigouche Bridge, Intercolonial Railway of Canada.

Ninth.—Within a coffer-dam where canvas is made use of instead of puddle, as at Mill Stream Bridge, Intercolonial Railway of Canada.

The Avon Bridge Foundations (*Plate No. 1*).—The substructure consists of five pairs of steel cylinders of from 35 to 48 ft. in height. They are each 5 ft. internal diameter, and are filled with concrete. The shells are $\frac{3}{8}$ in. in thickness; they are coupled together by laced beams and sway bracing. The coupling is sheathed over, making the pier dumb-bell shape in section. They are capped like doric columns. Two rolled I beams connect them over caps and form a base for the bridge seats and iron trusses to rest upon. This method of coupling the columns is employed, to unite their strength in resisting impinging blows of ice, as well as to keep the ice floes from getting caught in the bracing.

The columns rest upon limestone rock, carboniferous, and are secured to it. The manner of fastening the columns to the rock under water is, the writer believes, original, and he wishes to place it on record here. Limited means suggested its trial, and the result seems to justify its practice. A profile of the bed of stream, with depth of water at low tide, is as follows:

Commencing at the eastern or Windsor side of stream, the first pair of columns would be in 4 ft. of water, the second pair in 9 ft., the third in 9 ft., the fourth in 12 ft. and the fifth in 14 ft. of water. Neap tides rise 28 ft.; springs, 4 or 5 ft. higher. There were some loose boulders and a shifting sand, but as the width was contracted by the foundation work, the current removed the latter. The stones or boulders were readily removed by ordinary hand grappling. Cribs of wood were put together on the shore, and partially filled from ballast floors up, with sufficient stone to submerge them and preserve their buoyancy for floating to their destination. Two voids of 8 ft. square were left in each crib, to receive the cylinders. These cribs were floated into place at low water and sunk by additional stone ballast, so that the top stick stood clear over low water when sunk, and the voids were fairly over the sites to be occupied by the cylinders. The voids were next boarded over and the centers of cylinder positions marked upon them. From those centers a radius of 2 ft. 6 ins. gave the position or shell of each column. Next, within the radius nine equi-distant points were marked on the boards, and a large auger hole bored through the floor at each point, thus defining the periphery or outer

shell of the column when in place, and the position of nine dowels to be placed within it. The holes in the floor marked the position of the drill, and the floor itself acted as platform for the three men to work on, in the ordinary method of rock drilling. The workmen had no difficulty in drilling nine holes into the rock in this way, from 2½ to 3 ft. deep, nor in dropping dowels of 2-in. round iron into the drill holes. Thus there were within each tube nine iron dowels of 2 ins. diameter, standing to a height of from 2 to 4 ft. The cylinder was then lowered to its resting place, and the inside of the tube, as well as the 8 x 8 ft. void outside, filled up with concrete.

The method employed for placing concrete under water between the iron dowels proved very effective. Bags, made of rough brown paper well stiffened with glucose, were employed and slipped into the water over the required place of deposition. Each bag held about one cubic foot of concrete; smaller ones were used between dowels. The bags were quickly made up and dropped one after another, so that the one following was deposited before the cement escaped from the former one. The paper was immediately destroyed by submersion, and the cement remained; it could not escape. The bags cost $1.35 per hundred, or 35 cents per cubic yard.

The same practice adopted for the foundation of Avon Bridge can be employed in from 15 to 18 ft. of water. With the help of a diver it can be carried on in greater depths. The writer claims that the means employed to put in the foundations of Avon Bridge have been cheap and practical and effective, and the results have fully justified their adoption.

The work in connection with foundation and crib work was commenced by the Government during the first week in May, and continued without obstruction, accident or intermission. The first sections of the first pair of cylinders were set in place by the Dominion Bridge Company on July 19th, and the other four pairs were in position August 19th following. As each bottom section was fixed it was immediately filled with concrete, and levels taken on it and forwarded to the Dominion Bridge Company, so that the exact height of each tube to the top might be given to the men in the workshops.

Plate II illustrates the means adopted to obtain foundations for two pair of tubes to support the metal superstructure of Board Landing Bridge near Truro. The bridge crosses Salmon River before it

discharges into Cobequid Bay. The bed of the stream consists of quicksand or fine silt overlying a rock bottom of new red sandstone to a depth of from 5 to 7 ft. Neap tides rise 15 ft.; springs, about 18 ft. Enclosures such as coffer-dams or caissons, to exclude the water and the silt, would be too expensive, and dredging without such protective aid would be impracticable. The problem then became one to find, with the least possible expenditure, a solid bearing for tubes or for concrete or masonry piers of sufficient lateral strength to resist such heavy ice floes as run with the stream during freshets or during the "ogres" or "bores" so characteristic of the tidal rivers emptying into Cobequid Bay or into the Bay of Fundy. The strata being of a yielding semi-fluid nature it was quite practicable to sink the cylinders by dead weight to the rock, or to sink them by the pneumatic process and pump out or force out the quicksand. It was, however, considered that a greater lateral degree of resistance should be provided, to resist the ice jams, than the tubes and their connections could afford in this case. Something stronger and more cumbrous was deemed preferable.

Two rows of close piling, one on each side of foundation, along the longitudinal direction of the pier, were first driven, between wales, to the rock by a small pile-driver; the up and down stream ends of the parallel rows were left unconnected. The width of the stream was narrowed by the piers of the old bridge and by the new work and contracted the water-way so as to create a current of much greater intensity, and this accelerated flow was made to flush and scour out the sand, by directing it through the piled enclosure. Plate III fairly illustrates the method of getting rid of the quicksand. A mattress of brush and small stones was next lowered to the rock; the sheet piling of the ends of the enclosure and two clumps of piles to found tubes upon were next driven through the mattress to the rock, and the whole rectangular block filled with stone and brush to the level of low water. There are no marine borers about the littoral waters of Cobequid Bay, the water is too muddy; they would be sealed up in their burrows by the silt. The tubes were founded as shown by Plate II and filled with concrete.

Plate IV shows the method of preparing foundations for cylinders, the bottom being a hard boulder clay intermixed with large boulders. Bridgewater Bridge carries the highway traffic from the main street of

the town of Bridgewater over the La Have River to the railway station. The abutments are of granite masonry. The piers are built of unusual strength, to resist blows from rafts of timber, or the possibility of being carried away by jams of logs that are occasionally set adrift by freshets from the booms in the mill ponds up-stream. The foundations of each pier support three steel cylinders of 4 ft. internal diameter, each filled with concrete. There is nothing remarkable in the plan adopted except that it shows a cheap and effective method of dealing with a bottom of so refractory a nature, without the aid of coffer-dams or caissons. The bridge is near the "head of the tide"; a large body of fresh water passing through prevents damage to the submerged timber by the *teredo* or the *limnoria*. The two granite abutments and retaining walls out of stream cost $5 717, while the foundations of the two piers within stream, up to the level of low water, cost $2 010. The plan submitted will illustrate the manner of construction. The masonry of the abutments was let by contract at $8 per cubic yard. The work on the piers under water was performed by "day's work."

Plate V shows the method now being employed for constructing the foundations for Lockeport Bridge in the County of Shelburne. The bridge is to convey the traffic of the highway and of a narrow-gauge railway from the town of Lockeport, Lockeport Island, across a tidal armlet to the main land. The roadway crosses a small island with from 400 to 500 ft. of shoal water on either side and a channel of about 300 ft. in width, available for floating vessels through when launched from ship-building yards further up. The bottom, for a depth of 16 ft., is very soft, peaty mud overlying stiff clay. The water is from 3 to 4 ft. deep on the flats and about 10 ft. in channel at low tide. Neap tides rise 6 ft.; springs, 8 ft. The roadway over the flats is being constructed upon a broad base of mattresses and faggots of brush, and the channel is being bridged with a steel swing bridge to revolve on a circular concrete pier and two fixed spans supported by steel tubes. All rest upon artificial foundations of piling.

The *limnoria lignorum* is active in the Harbor of Lockeport, showing the necessity of having the timber piles protected by an outer wall or covering of concrete. The hexagonal block of sheet piling and the rectangular blocks of piling round the tubes are driven merely to retain the concrete. The plan shows all other details of construction for foundations and for substructure.

The plan adopted for dealing with the foundations of Sutherlands River Bridge, Eastern Extension Railway (see Plate VIII), could be also fittingly selected for the foundations and substructure of Lockeport Bridge. A careful examination of the conditions and costs showed, however, that a saving of from 30 to 35% would be effected in favor of the method now being employed at Lockeport, and the cheaper plan was accordingly followed. The cost of foundations and substructure of the circular pivot pier and for the four pair of tubes to support the two fixed spans, up to the level of low water, will not exceed $5 000.

Plate VI shows foundations and circular pier of a swing truss, built over the navigable channel of the Little Bras d'Or, Cape Breton. The bottom or bed of channel is of soft mud and clay, the denudation of the carboniferous strata of the district. The principal feature to be noticed is the plan adopted for building the pier to support the swing bridge and securing foundations therefor.

All round the site of this bridge, as well as its environs, is a favorite haunt of the *teredo navalis* or the *teredo norvegica*, Spengler, more probably the latter. The bridge consists of one swing span, 162 ft., and a fixed span of 80 ft. To better subserve the requirements of navigation, the pier on which the swing revolves stands in 28 ft. of water at low tide. The pier consists of a center cylinder 4 ft. in diameter, surrounded by six cylinders of 3 ft. diameter each, all coupled together above water level with laced beams. The pivot on which the swing revolves, rests on the center tube, and the six other tubes support a track resting on rolled I beams covered with $\frac{3}{8}$-in. plate. The foundations of the tubes consist of clumps of piles, cut off at level of the bed of the stream by machinery, one pile in the center of each clump having been cut about 6 ft. higher up. The tubes are filled inside with concrete to top, and outside with concrete and stone to a height of 15 ft. from the bed of the stream. The outside piers and abutments are built of Georgia yellow pine, creosoted by Eppinger & Russell, Brooklyn, N. Y. The whole work cost $19 000.

Plate VII illustrates the system employed for obtaining foundations for the fixed spans of the bridge constructed in 1888 to replace the Victoria Bridge, Bear River, which consists of a swing span 160 ft. in length, two fixed spans of 125 ft. each and one of 100 ft. The swing span revolves on a circular pier 24 ft. in diameter, constructed entirely

of concrete. Each pier for the fixed spans consists of two wrought-iron cylinders, 5 ft. each in diameter, filled with concrete, coupled together by laced channel beams and lateral bracing, and sheathed between main tubes, to prevent lifting or displacement by ice floes. It is, however, the circular or concrete pier that comes most properly within the bounds of these remarks. There is 18 ft. of water at ordinary low tide; springs rise 29 to 30 ft. The *limnoria lignorum* is here so active that the bearing power of piles, or of timber submerged below the level of low water, is, where exposed, affected, if not destroyed, within six years. The supports of the old wooden bridge had to be renewed twice within a period of 12 years. The new bridge is placed immediately above the old one, and if founded on piles similarly unprotected would be no more reliable. The foundations are so liable to scour by the rapid running tides or ogres, so characteristic of the Bay of Fundy, on loose gravel deposits, that piles were considered safer to found upon. For these reasons, as well as for one no less obvious, viz., limited means, it was decided to adopt piles driven 3 ft. apart at centers over the whole base of pier, and to protect them with a circular envelope of concrete 3 ft. in thickness. The hexagonal circuit of close piling shown by figure No. 7 is driven merely as a mold to retain the outer wall of concrete while it is being erected. The piles were cut off at the level of low-water spring tides, the intervening spaces between them filled up with small stones, and the usual platform, 12 x 12 ins. timber, framed thereon, thus completing the circular pier up to the level of low water. The concrete superstructure from that point upwards to finish is a frustrum of a cone, having a solid vertical central pillar 4 x 4 ft. to support the pivot and four walls, 2 ft. 6 ins. each in width, radiating therefrom to the outer circular wall, or periphery, which is 2 ft. 6 ins. wide at top and increases downwards with a batter of 1 in 8 ins. The four voids thus left in the body of the prism have vertical sides to within 4 ft. of the top, where they corbel to an apex and are covered with 2 ft. of fine concrete. The columns in deep water supporting the fixed spans rest on clumps of piles cut off at the bed of the river by a circular saw, two piles being allowed to stand up within the body of the tube, to prevent displacement. The spaces outside the tubes to the sheet piling, as well as within the tubes, are filled with concrete, outside to level of low water and inside of the tubes to top. The cost of the bridge approaches and mooring piers amounts to $52 000.

There is not much difficulty experienced in cutting piles under water in the same plane, and at any desirable depth up to 30 ft. Such arrangements can be made above the water level as will ensure their being cut off one by one, perfectly level below. The outer rows of sheet piling having been driven and cut off close to the wales at Victoria Bridge, served as a bearing or platform to rest the framework of pile-driver upon, to cut the inner or bearing piles as close to the bed of the river as the surface of ground would allow the circular saw to work. The shafting of the saw can run in pedestals, set in a frame standing vertical, or can be set along the leaders of the pile frame and adjusted to cut at the required depth below the surface of the water. A circular saw of 3 ft. diameter, with shafting, 2½ ins. diameter, set in a pile frame and worked from a pulley off vertical shaft, with a twist in the belt to change the direction of motion, will freely cut piles to a depth of 30 ft. below the water level. Care must be taken to have the platform on which the machine is moved along as the piles are cut one by one, level, so that the saw working below will enter every pile and cut them off at the same uniform level all round. The belting is run by an engine worked from a scow, and can be made, by the application of a lever, to work in a rising or falling tide without slip or displacement. When well directed by a skillful mechanic, each pile can be cut off in 20 ft. of water in 25 minutes, including the time lost in shifting the machine from one pile to another.

Plate VIII represents the method employed for constructing foundations and substructure of Sutherlands River Bridge, Eastern Extension Railway. This bridge carries the line of railway over a shallow estuary into which Sutherlands River empties at the head of Merigomish Harbor. The bottom is of a semi-fluid lacustrine nature, consisting of silt and peaty deposits for a depth of from 8 to 16 ft. At low tide there is not more than from 2 to 3 ft. of water on the flats, upon which the railway is carried by an embankment resting on faggots of wattle and brush. As the flow of tide is thus impeded, a greater current is created in the channel, over which the bridge of 160-ft. span is built. There is now 10 ft. depth at low water in the channel. Neap tides rise 5 ft.; springs, 6½ ft. The teredo is found boring in submerged wood in the harbor, and its appearance was feared here. In this case artificial foundations had to be provided, in a very soft, yielding strata, liable to scour, and to the attacks of those destructive mollusca.

A row of close piling was driven along the face and around the exposed ends of each abutment, and bearing piles at 3 ft. apart centers, under the base of the masonry prisms. These piles were all cut off level by a circular saw 8 ft. below low water. A water-tight caisson, built on shore, launched and filled with ashlar masonry as high as its buoyancy would permit, was floated into its true position, over the piles, and sunk by the addition of more masonry until the abutment was clear of water. After the abutments were completed rip-rap was carefully placed all round the exposed timber, as is shown by the illustration.

Plate IX and the following extracts are taken from the "History of the Intercolonial Railway," by Sandford Fleming, Esq., Chief Engineer, C. M. G., pp. 163–165. The writer of this paper was the contractor for the foundations and substructure.

"The River Restigouche constitutes the boundary between Quebec and New Brunswick. The railway bridge connecting the two Provinces is the only bridge which crosses the river. It is situated below its confluence with the Metapedia. After emerging from the contracted valley through which the Metapedia flows, the railway turns almost at right angles, to follow the Restigouche. The main stream for some distance is hemmed in between high steep hills, rising abruptly to a height of from 500 to 700 ft., and the sudden change in the direction of the railway necessitates the construction of the bridge on a skew of 45°."

"The hills are composed of a metamorphosed slate, much contorted and so tilted that the direction of the cleavage is not easy to determine. The river takes the direction of the strike and has, no doubt, shaped its course from denudation. Blue clay underlies the gravel in the bed of the river, but it is undoubtedly local."

"Soundings and borings were made through the ice, early in 1869, which led to the opinion that the bed of the river was rock, overlaid with some inches of gravel. But it was found that stones imbedded in gravel were the hard substance met, and that the solid rock was at a much greater depth. The outcrop of rock on both sides of the valley suggested that the stone in the gravel was rock *in situ*. Subsequent borings, however, showed the gravel to extend from 7 to 10 ft., underlying which plastic blue clay is found."

"At Pier No. 1, rock was reached at 53 ft. under the summer level of the river; at Pier No. 2, at 75 ft.; at Pier No. 3, at 62 ft., and at Pier No. 4, at 54 ft.

"Accordingly, piling was necessary in all the foundations, except for that of the easterly abutment, which was built on the rock. The

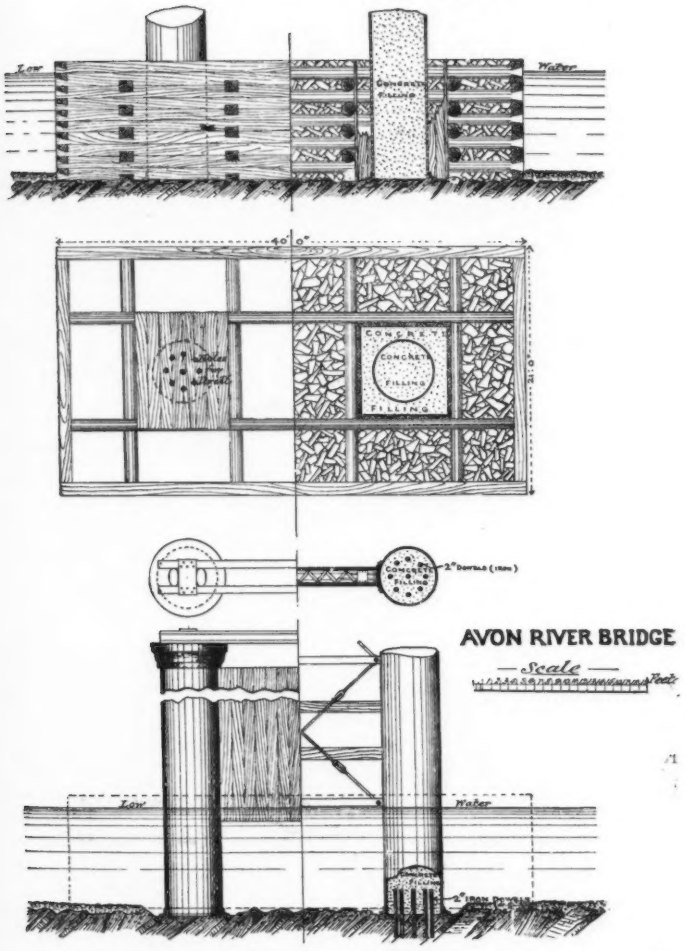
work of piling was continued throughout the winter, that season being suitable for this operation, the ice forming a platform for the machinery. The coffer-dams were protected by triangular-shaped cribs to act as breakwaters, so constructed as to prevent injury to the works from the ice."

"The pumping was effected by five engines, with an aggregate of 70 H. P. Centrifugal pumps, capable of discharging nearly 6 000 galls. per minute were used. Owing to the stratum of gravel, and the heavy flow of water, the excavation was performed with difficulty. The pier foundations consist each of close square piling, enclosing an area of 102 x 16 ft., with four rows of intermediate piles, 3 ft. apart. The space between the piles was filled with concrete, and a platform was constructed upon them 8½ ft. under water, so as equally to distribute the weight of the superincumbent masonry. Much difficulty was experienced in the execution of these works in a deep and rapid river."

"The pile-driving, of more than 60 000 linear feet of timber, was carried on almost continuously from August, 1872, until April, 1874. Ice begins to form in this river in November, and although the rapids of the river remain for some time open, where the current is slight, ice sufficiently firm to carry a man will form in 24 hours. From November until March, but little rain falls, the thermometer ranging from 32° above to 32° below zero. The average, during the five years occupied in constructing the bridge, was slightly below zero. A change in the weather, when the winter sets in unusually early, accompanied with rain, will occasionally raise the water and break up the ice, producing 'ice jams.' The Metapedia is especially liable to these incidents; in the Restigouche they are not common. The low temperature as a rule, from November to March, produces ice from 2 to 4 ft. thick, and about the end of March it reaches its maximum strength. Moreover, the ice is not confined to the surface of the river. As in many northern localities, anchor ice is developed to a great extent, sometimes to double the thickness of the surface ice. It is not, therefore, surprising that at the end of winter a sudden thaw, raising the water of the main stream and setting adrift the whole winter ice, should produce astonishing results. Floating down stream, these masses of ice meeting with obstructions will pile one on the other, until a 'jam,' completely across the river, is produced."

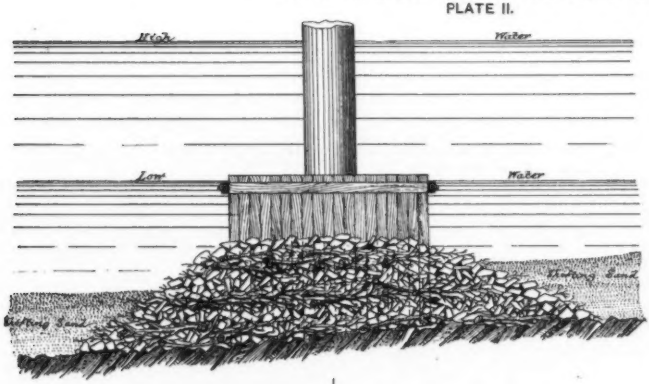
"The water thus dammed back will in a few hours rise to a height, sometimes of 20 ft. The 'jam' ultimately gives way, and a moving mass of ice, water and uprooted trees is borne onwards, often with a current of 7 or 8 miles an hour."

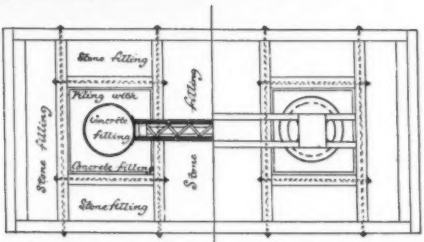
"The river Restigouche is liable not only to these 'ice shoves,' but to occasional freshets; the most marked of which, the 'spring freshet,' occurs yearly with regularity at the end of May or beginning of June.

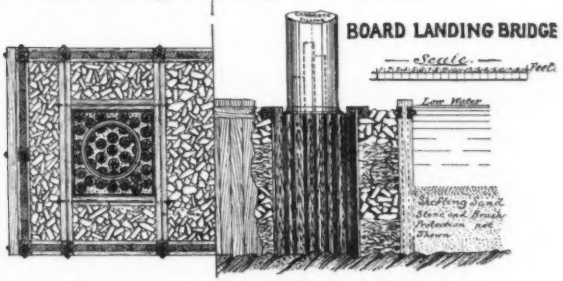


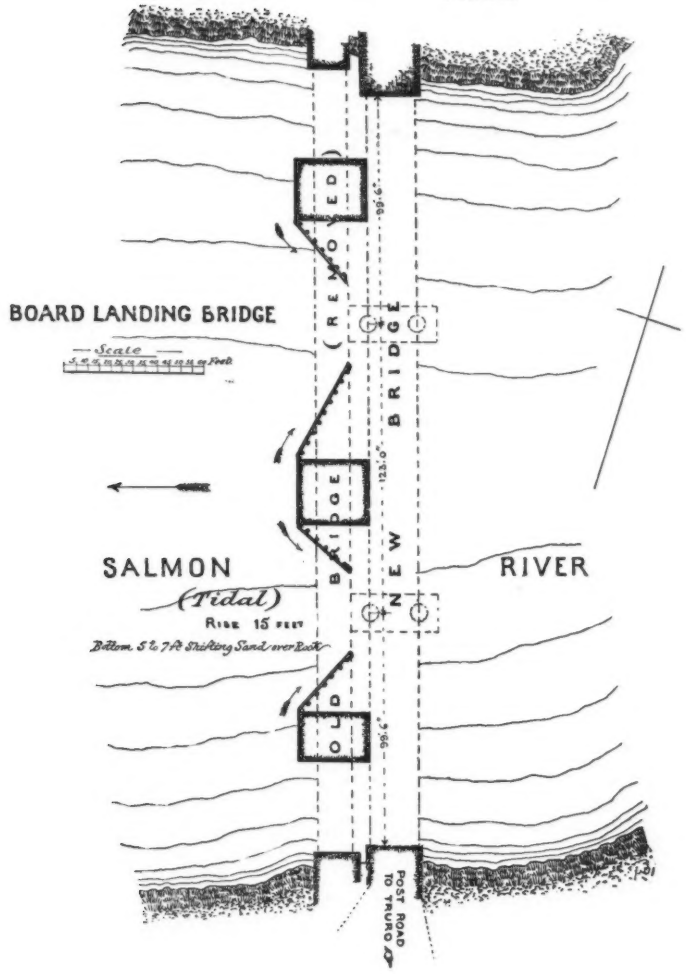
AVON RIVER BRIDGE

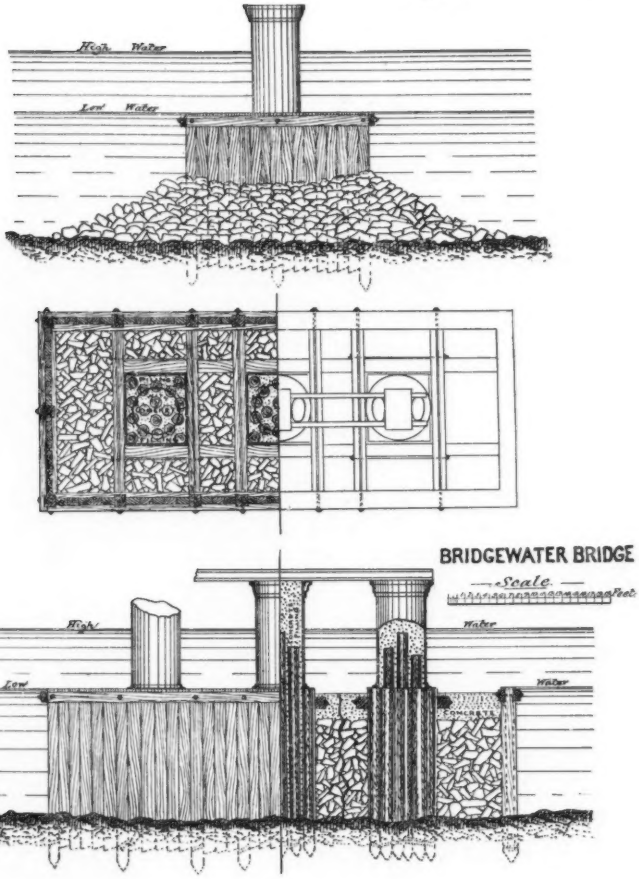
— Scale —
Feet


High Water
Low Water
Low Water
Shifting Sand
Shifting Sand


Stone Filling
Filling with Concrete Filling
Stone Filling
Stone Filling
Concrete Filling
Stone Filling
Stone Filling


BOARD LANDING BRIDGE
Scale
Feet.
Low Water
Shifting Sand
Stone and Brush Protection not Shown


BOARD LANDING BRIDGE
Scale
(REMOVED)
99.6'
BRIDGE
123.0'
NEW BRIDGE
SALMON
(Tidal)
RIVER
RISE 15 FEET
Bottom S & P& Shifting Sand over Rock
OLD BRIDGE
99.6'
POST ROAD TO TRURO


High Water
Low Water
BRIDGEWATER BRIDGE
Scale.
Feet.
High Water
Low Water
Water
CONCRETE

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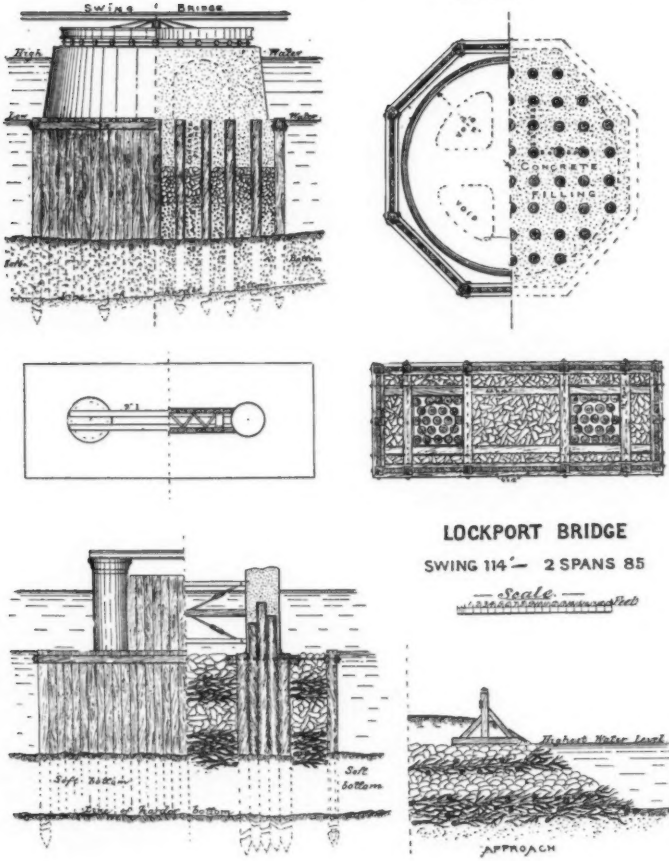
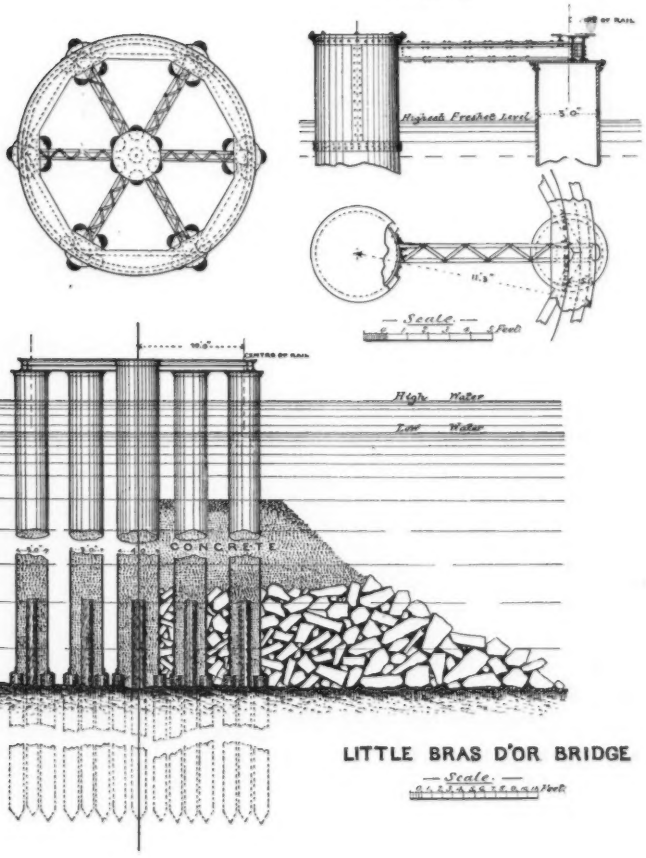
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE V.



LOCKPORT BRIDGE

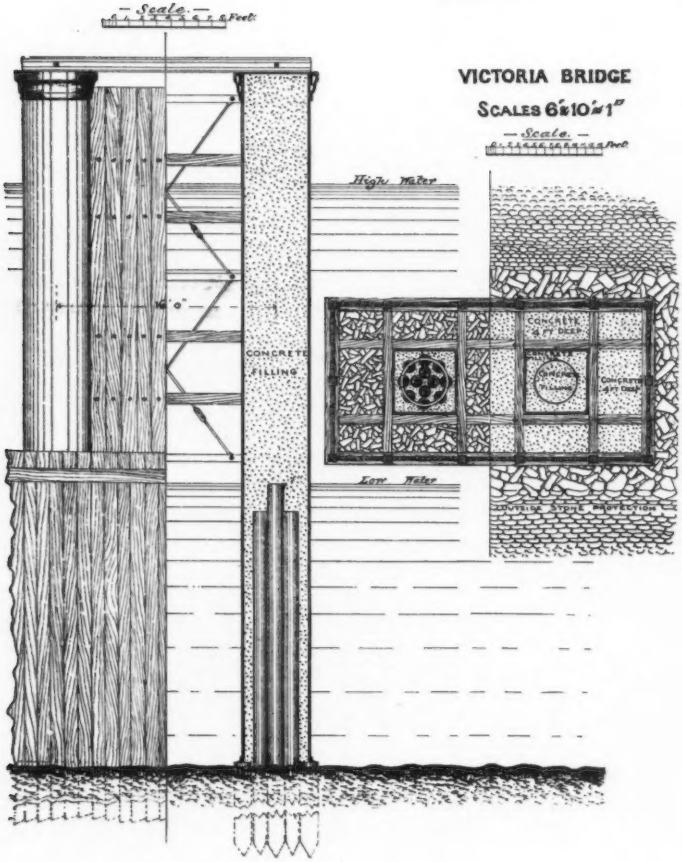
SWING 114'— 2 SPANS 85

— Scale. —



LITTLE BRAS D'OR BRIDGE

— Scale. —


— Scale. —
VICTORIA BRIDGE
SCALES 6 & 10 ft = 1"
— Scale. —
High Water
CONCRETE FILLING
CONCRETE & CUT STONE
CONCRETE FILLING
CONCRETE & CUT STONE
Low Water
TRIPLE STONE PROTECTION

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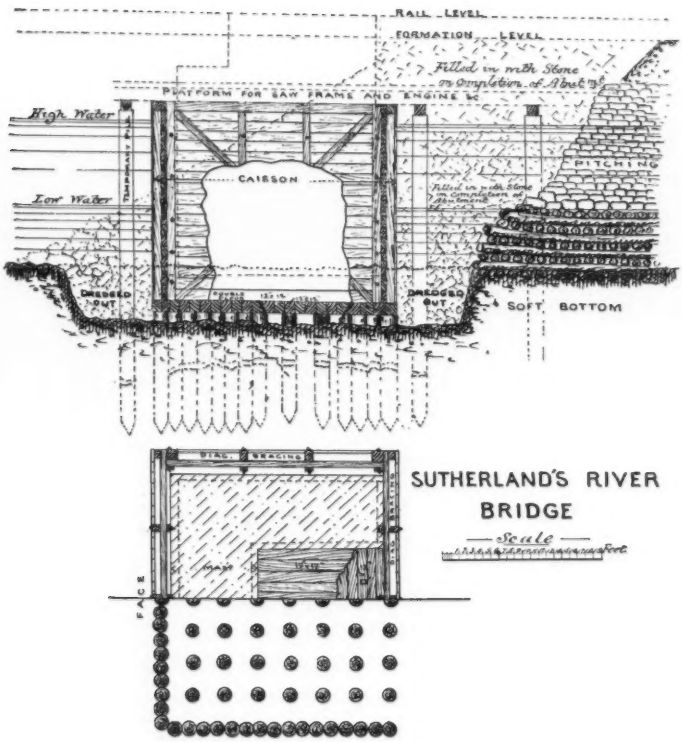
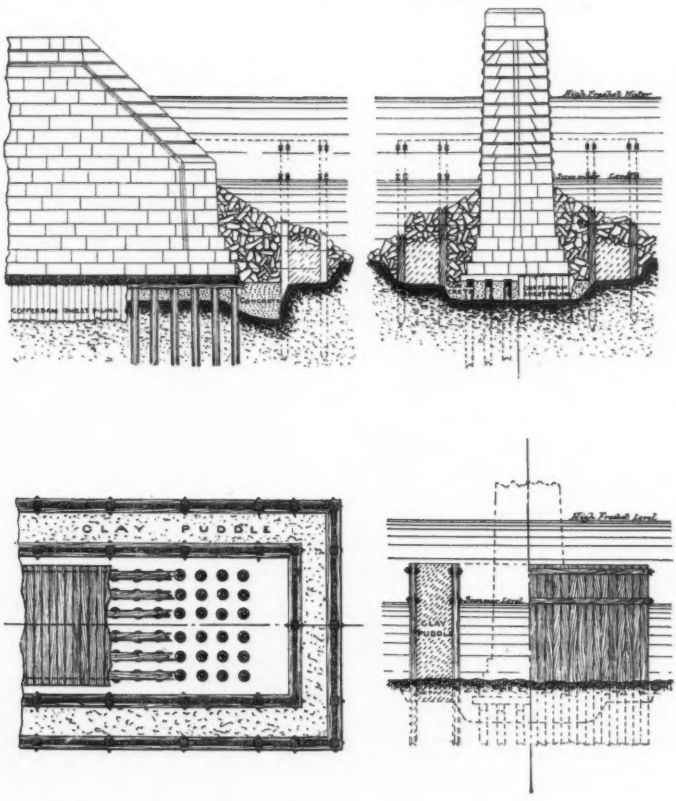
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE VIII.

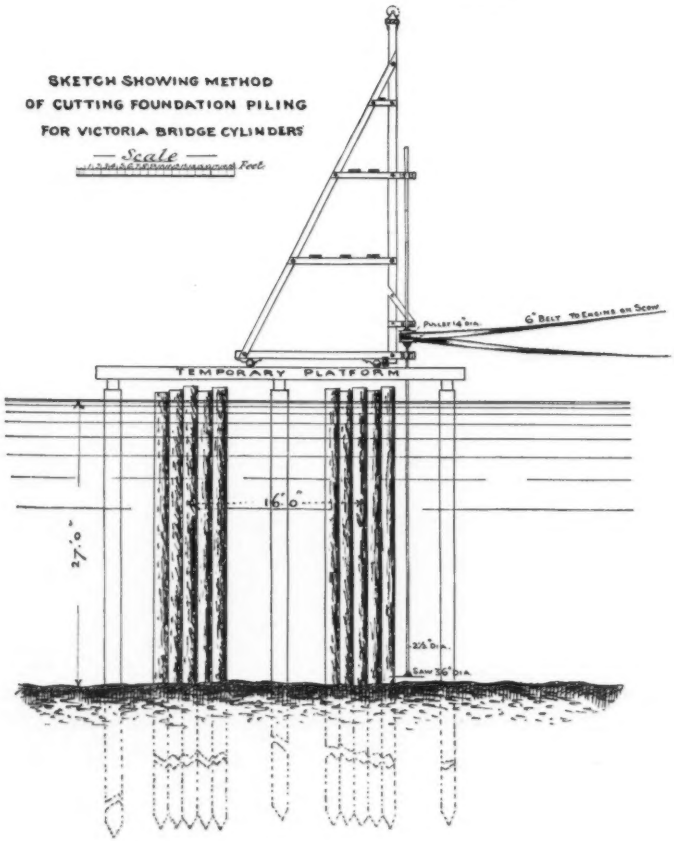




FOUNDATIONS RESTIGOUCHE BRIDGE, INTERCOLONIAL RY.

SKETCH SHOWING METHOD
OF CUTTING FOUNDATION PILING
FOR VICTORIA BRIDGE CYLINDERS

— Scale —
Feet.



So regular is this periodical flood that it is annually anticipated. The spring freshet is distinct from the 'run of ice,' several weeks intervening. It always occurs immediately after the warm weather sets in and is due to the melting of the snow in the uplands, where the tributaries take their rise. This freshet usually raises the Metapedia 12 ft. and the Restigouche 18 ft. above ordinary summer level. The rise of the water is gradual, and still more so is its fall; the former generally occupies several days, and the latter as many weeks; the river rarely assuming its ordinary level until the last week in June."

"The Restigouche has been famous for its lumbering operations for half a century, and a great quantity of timber is still cut on its banks. The contingency of rafts and drift logs striking the piers and endangering the superstructure had to be provided against."

"Every precaution has been taken to render the piers of the bridge capable of resisting the formidable forces to which they will periodically be exposed. It is believed that they will remain uninjured."

"It has been stated that the masonry is built on a pile foundation, except in the easterly abutment, which is built on rock. Although, owing to the current, the ice impinges with great force on that side of the river, the foundation being well let into the rock, and the wall being well built and protected, no injury is likely to result."

"The masonry, generally, is built of stone found in the adjoining railway cutting, on the south-easterly bank, where blocks of good dimensions were obtained. The work is executed in courses, 30 ins. thick on the footings and 24 ins. in the body of the work, the blocks being from 6 to 8 ft. long."

"The stone is tough and well adapted for work requiring great strength. Being difficult to dress, however, except in the line of cleavage, it was decided to use granite for the cut-waters and quoins."

"The granite was brought from the River Nepissiguit, beyond Bathurst. It is not unlike the well-known Aberdeen granite, the scales of mica only being somewhat smaller."

"The distance from the quarry is nearly 90 miles, 70 of which only were by open navigation. The blocks were therefore prepared in the quarry, and, when reduced to their proper size, weighed from 3 to 9 tons each."

"The necessity for great strength is evident from the foregoing account of the phenomena yearly witnessed in the river, which no light structure could resist. The face stones of the cut-waters, the coping, bridge seats, and the two upper courses of ashlar, together with the skew quoins on the down-stream end of piers, are granite. A striking contrast is accordingly obtained to the dark slate color of the body of the masonry, which adds to the appearance of the structure."

"The total quantity of masonry exceeds 6 000 cu. yds.; the whole is built in Portland cement, and the exposed parts of piers were

secured by strong iron clamps, so contrived that it would be impossible for floating logs or ice to disturb a single stone without moving the whole mass to which it is attached. The work was commenced in the summer of 1870 and completed by Christmas, 1875. During the whole of that time, notwithstanding the heavy plant and material employed, not a single serious casualty occurred."

The foundations and substructure cost $276 000.

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(Vol. XXIX.—September, 1893.)

IMPROVED METHOD OF CONSTRUCTING FOUNDATIONS UNDER WATER BY FORCING CEMENT INTO LOOSE SAND OR GRAVEL BY MEANS OF AIR PRESSURE.

By FR. NEUKIRCH, C. E., of Bremen, Germany.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

This improved method of constructing foundations has for its object to convert the sand or gravel, existing under water at the locality where the foundations are to be made, into a solid body in the form of sand or gravel concrete. This conversion is effected *in situ*, so that no excavation to the solid bottom is required. The sand is converted into sand concrete by forcing cement in the form of powder, as it occurs in commerce, through a pipe by air pressure into the submerged

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

sand. The pipe has an internal diameter of about $1\frac{1}{2}$ ins., and is drawn to a point at the lower end, in which there are three or more holes of about $\frac{3}{8}$ in. diameter. The upper end is connected by a bend and rubber tubing with the air-pressure supply pipe in such manner that the pipe can be raised, lowered and moved while the air pressure is flowing through it.

In the air-pressure supply pipe, provision is made by means of suitable branches and stop-cocks for connecting therewith an apparatus which by means of an injector device enables any desired quantity of cement powder to be fed into the air current. The air pressure, together with the cement powder, issues through the small openings at the lower end of the lance pipe, and is driven with considerable pressure into the sand foundation ; this is very mobile as it is entirely under water, and consequently the blowing in of the cement produces a motion in the foundation pit similar to that in a vessel of boiling water, the steam bubbles instead of air bubbles being formed. The cement carried by the air is retained by the wet sand and combines with this to form sand concrete.

By the boiling motion an intimate mixture of the wet sand with the cement is effected.

After the injection of air has ceased, the grains of sand in subsiding adhere very firmly together, and experiments have shown that a natural bed of sand, after having one-fifth of its volume of cement injected into it, will after the operation occupy a smaller space than before ; this was shown by the fact that the surface of the sand concrete lay deeper than that of the surrounding natural sand-bed.

The introduction of the lance tube into the sand-bed is effected by first blowing air through it, so that the air issuing from the lower end forces back the sand and in setting it in motion renders the sinking of the tube to considerable depths, such as 16 to 19 ft., readily possible in a comparatively short space of time; this operation is rather more difficult only when the bed is not purely sand, but contains larger stones, wood, etc. In this case it may be necessary to raise the tube up again and to insert it at a different place so as to avoid the obstructions.

In order to insure a uniform mixture in the foundation pit, it is divided into small fields of from 8 to 12 ins. square, and into each of these the required quantity of cement, which is ascertained by dividing the cubic contents of the field by the required proportion of the

admixture, is blown. The lance tube is first sunk in each field down the solid substratum by means of air pressure alone ; when it has attained this depth, cement is supplied to the air current, and during the continued introduction of the cement powder the tube is slowly drawn upwards until the required quantity of cement has been introduced.

In order to enable the lance tube to be readily handled, it is suspended from a tripod or traveling stage having a small winch by means of which the tube can be readily raised and lowered. The movable stage has the advantage that it enables every field of the foundation pit to be easily reached. The steam-boiler and compressor for producing the air pressure can be placed at a greater distance from the foundation pit ; the air pressure can readily be conducted through wrought-iron pipes to the point required. It is of advantage to warm the air in the vicinity of the cement apparatus, as otherwise moisture might be separated by the cooling of the air, which would be very inconvenient in working and easily produce a clogging of the cocks and injector nozzles.

For warming the air a small cast-iron stove is employed, consisting of two cylinders inserted one within the other and connected together air-tight. In the inner cylinder is a fire grate on which a light fire is maintained. The air pressure is made to circulate through the annular space between the two cylinders. The inner cylinder has external ribs formed on it, so that the air pressure is brought in contact with a considerable heating surface on its way through.

The steam-boiler and compressor can be arranged as a portable engine, so as to enable the apparatus to be readily transported from one foundation pit to another.

This method of constructing foundations may be compared with the ordinary method of making concrete foundations, in a similar manner as the Bessemer process compares with the puddling process in the manufacture of iron. In the Bessemer process the blowing of air into the molten pig iron causes the carbon to be burned and a solid metal steel is produced, while in the puddling process this conversion is effected only by laborious stirring. In the new process of making foundations the blowing of the cement into the stratum of liquid sand, as it were, converts it into a solid body, while up to the present time this was also only effected by laborious stirring.

As the entire process is mainly carried out by machinery and requires only a small amount of manual labor, foundations can be carried on rapidly by this process.

If it be desired to transmit the pressure which the foundations have to bear to a substratum below that upon which the sand-bed lies, this can be effected by driving in piles to the required depth before the cementing process is commenced. These piles will then be completely imbedded in the sand concrete and be firmly united therewith, so that they may be considered as part of the structure.

If it be desired to sharply limit the lateral dimensions of the body of sand concrete, or to protect it against external influences, the foundation pit is in the first instance surrounded by a coffer-dam.

The hardening of the sand concrete formed as above described takes several weeks, and the complete hardening, several months, as in the case of ordinary concrete under water.

On the accompanying drawing (Plate I) is shown the necessary plant for carrying out the above-described process, as also the application thereof for some cases.

Fig. 1*a* shows the arrangement of the steam-boiler, compressor, air reservoir and heating stove for the air-pressure supply, which should always be situated near the place of operation. Fig. 1 shows the application of the process for consolidating the soil round a brick sewer so as to insure its being water-tight against the surrounding aqueous sand stratum, and to afford it a rigid bed therein.

The sewer, which is 5 ft. internal height, lies in quicksand, and had become so leaky that the sand penetrated into it in considerable quantity. Owing to this, the road pavement and also the neighboring houses subsided, so that it became urgently necessary to provide a remedy. This could not readily be done in the usual manner, as it appeared very hazardous to drive coffer-dams in the somewhat narrow street. By applying the above-described invention the sewer was made perfectly tight and secure for a length of about 500 ft.

Fig. 2 shows an application of the process in the harbor of Vegesack near Bremen. For the quay wall a bulkhead of rolled iron was used. Wood could not be used for this purpose, because the bed is very stony, and because in consequence of the ebb and flood the dam is not always altogether under water. Such iron dams are with diffi-

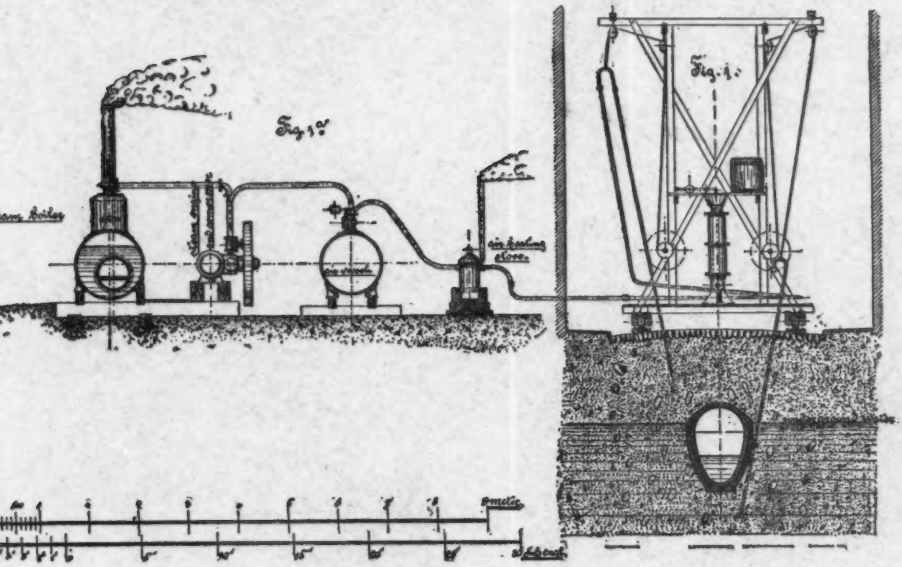
Fig. 1.
Fig. 1a.

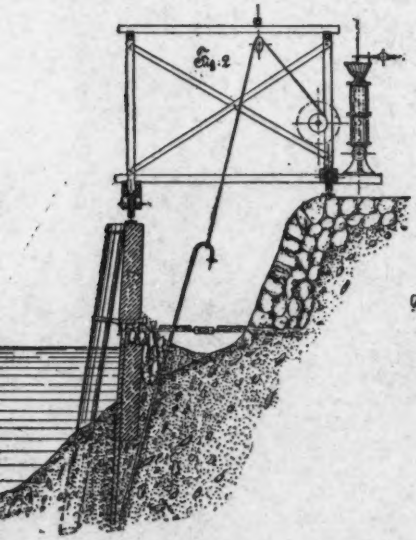
Fig. 2

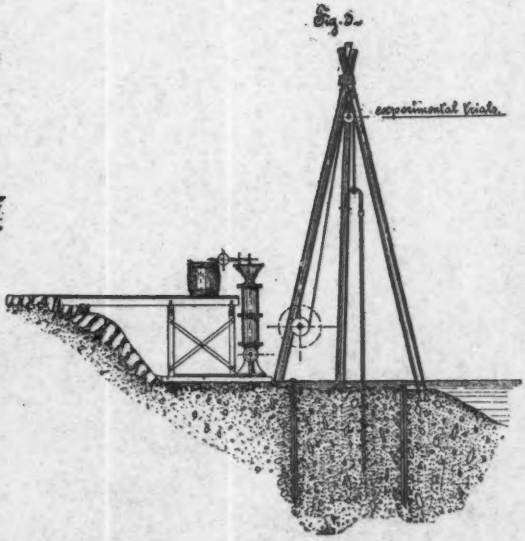
Fig. 3.
experimental trials

culty made completely tight. By blowing in cement behind the dam, it was rendered perfectly tight and safe.

Fig. 3 shows the arrangement employed for experiments.

A simple tripod is in this case erected for suspending the lance tube, while in the previously described arrangements a movable frame was employed.

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AMERICAN GRAIN ELEVATORS.

By E. LEE HEIDENREICH, Member of Scandinavian Eng. Society of Chicago; Am. Inst. Min. Engrs.; Western Society of Engrs.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The handling of cereals on a vast continent naturally becomes a problem of, not only national, but universal prominence, and ever since the forties it has been considered one of the principal problems encountered by the commercial element of the United States. Realizing the importance of making a *résumé* of the progress of construction of American grain elevators as short and concise as possible, owing to the large number of papers to be brought before this distinguished assembly, the writer will confine himself to a description of modern elevators merely, without touching upon the history of grain handling in America any more than is absolutely necessary.

The *modus operandi* of a grain elevator is about as follows:

1. A power car-puller sets a string of cars each opposite an elevator leg, or vertical grain conveyor, located about a car-length apart.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

2. Car-doors are opened, two shovelers enter each car and handle each a shovel operated by rope from a power-shovel shaft in the elevator.

3. The grain drops into a receiving hopper, is elevated in buckets bolted to a rubber belt 150 ft. to the top floor of a cupola, where it is discharged, in turning over a head pulley, into an accumulator, or garner, and thence into a weighing scale.

4. From the scale the grain is spouted;

a. On conveyor belts running horizontally and discharging over movable trippers into storage bins. (Storage elevators.)

b. In car spouts for reloading or transferring. (Railroad transfer elevators.)

c. Directly into storage bins.

Into shipping bins with dock spouts, to be loaded into vessels.

Into car spouts. (Terminal elevators for rapid handling and storage.)

d. Into garners above cleaning machinery. (Cleaning elevator.)

5. When the cars are empty the shovelers take with them the power-shovels across the working floor (about 14 ft.) to a string of cars set in on the opposite side of the elevator, where the performance is repeated, while the first string of empty is being replaced by loaded cars.

In addition to the four classes of elevators mentioned we have the marine elevators, receiving grain in bulk from vessels—usually by means of one stationary and one movable marine leg—so as to unload two hatches simultaneously. The grain is elevated into a garner, weighed and re-elevated, or spouted, on conveyors into storage, or transferred into cars.

The sixth class of elevators are the small country houses, or railroad station elevators, where grain is weighed in farmers' wagons and dumped into a pit, elevated, stored, and for shipment re-elevated, weighed in a hopper scale and spouted into a car. The accompanying plates explain themselves, and, as there is nothing that can interest an engineer in their construction, no further reference will be made to them.

The Construction of Storage Elevators.—The want of additional storage at a railroad terminal is usually dictated by immediate demand, and for this reason this class of elevators is constructed usually with greater attention to cheapness and rapid completion, combined with

strength, than to mechanical details. There have been cases where the problem has been put to an elevator builder in this way: "We want 3 000 000 bushels of storage, with a handling capacity of 200,000 bushels per day, constructed complete within 45 days; can you do it? and at what price? If the builder says, "Yes; I can do it at 5 cents per bushel," the contract is signed and operations commenced at once. An excavation is made about 18 ins. deep, if in clay or sand, and the same covered with hewn railroad ties in such manner as to get the entire surface as a basis for the superimposed load. Three or four timbers are laid side by side in bents from 11 to 14 ft. apart across the ground, and from 12 to 50 ft. longitudinally. Short cross corbels are rested thereon, supporting cross and longitudinal timbers, upon which the cribbing is spiked. The cribbing consists of pieces of 2 x 8 or 2 x 6 common pine or hemlock, usually surfaced one side and one edge, laid flat on the top of each other, and spiked with 30d spikes every 12 ins., zig-zag. The two first cross bents of the elevator are usually built on posts, so as to form a working floor from 20 to 28 ft. wide across the width of the elevator. Here are located the elevator legs, or vertical grain conveyors, at a distance of from 36 to 40 ft. from center to center, according to the length of the freight cars. These legs extend into the ground about 12 ft. from the working floor, so as to be able to take grain from a receiving hopper, extending to a point between the rails of a track running alongside the front of the elevator as close as the cars will permit. The angle of the receiving hopper with the horizontal is in the neighborhood of 35°, or 2 to 3, so that the corners of the receiving hoppers will clean themselves of oats. The height of the planking, in the rear or storage part, varies considerably according to the value of the building site, and runs from 40 to 85 ft. in height. Above the planking, *i. e.*, above the bin floor, a so-called cupola is erected directly over the space before designated as a working floor. In this cupola a series of scales for weighing the grain received or shipped is located, and inasmuch as, particularly in shipping, the elevator legs receive grain all the time, it is usual to locate, immediately beneath the discharge spouts of the elevator legs, a garner or accumulator above each scale for the purpose of receiving the grain while the scales are weighing and unloading. Another system of somewhat older date is to use two scales, called twin scales, for each elevator, accomplishing the same purpose. On the bin floor immediately

beneath the scales and extending longitudinally with the elevator, is a series of grain conveyors, consisting simply of endless belts varying in width from 16 to 40 ins., on the upper line of which is located a so-called tripper, which is movable on a track running from one end of the elevator to the other. In receiving grain it is spouted down on said conveyors, and the tripper is located above the bin or reservoir in which the grain is to be stored. The speed of these belts in modern elevators is about 700 to 800 ft. per minute, and, although the surface of the belt is perfectly flat, the cohesion between the kernels of grain is such as to gather the grain towards the center of the belt in such manner that from 2 000 to 20 000 bushels per hour can be conveyed. The bin bottoms in a storage elevator of this kind are usually flat, consisting of 3 x 14 joists, placed about 9 in. on centers, and covered with 2 x 6 dressed and matched flooring. Sometimes this floor is laid directly on the ties on sills, but this practice is not to be recommended, as it leaves less chance for ventilation. For unloading the grain from the elevator, belt conveyors are located along the bin bottoms at convenient distances so as to reach the front receiving or shipping legs, and are covered with planking or cribbing, or planking on the sides with timbers overhead, in such manner as to form tunnels, extending from the working floor to the end of the elevator.

In receiving grain from the cars, a train consisting of as many cars as there are receiving legs is detached by means of a power car-puller from a string of from 20 to 30 cars set in by a switch engine. Owing to the different lengths of the cars, they are detached and "spotted" or located each opposite a receiving leg. The exterior covering of a storage elevator is usually of corrugated iron, with a tin or aluminum alloy roof.

Inasmuch as the elevator legs must extend some 8 or 10 ft. into the ground, they are located in steel tanks of $\frac{1}{4}$ to $\frac{5}{16}$ material, and, to prevent the collapse of these by the pressure from the superstructure, it is a good practice to drive a few piles on each side of each tank and cap them with timber in such a manner as to bridge the tanks.

As for time, the principal item in rapid construction of this kind is to get the material on the ground. The planking or cribbing can be done at the rate of 6 to 7 ft. a day, so the main structure, from the top of foundation to the bin floor, can be finished in 12 to 15 working days, when properly managed.

Where the bins or grain reservoirs are more than 12 x 16 ft. area, they should be rodded. A good rule for calculating the rodding of a bin is to imagine a bin filled with grain, turned over flat and the side suspended by rods running through the grain. As the rods should not exceed $\frac{3}{4}$ in. or $\frac{7}{8}$ in. diameter steel, it gives a space between the rods in large bins of about 5 ft. square. Formerly the practice was to increase the diameter of the rods towards the bottom of the bin, but it has been proved that the horizontal pressure in a bin is practically constant from within 15 ft. of the top to the bottom. The reason for this is that grain such as corn, wheat and oats in bulk forms a peculiar bridging, leaving the pressure on the bottom, under ordinary circumstances, constant for any height above twice the width of the bin.

Experiments have given the load on an equilateral bin bottom as very nearly equal to the weight of a paraboloid of a height 1.8 times its base, and this fact led the writer to make the bin rods the same diameter from bottom to top of bin, with good results.

In some of the older elevators where the bin rods at the bottom were from $1\frac{1}{4}$ to 2 ins. diameter, it has been found that the down draft of the grain in unloading the bin bent the rods and pulled the washers into the bin walls, while the $\frac{5}{8}$ to $\frac{7}{8}$ in. rod seems to cut through this suction without damage. But for this peculiarity of grain, the construction of bin bottoms would present great difficulties, the static load figuring up to 4 000 lbs. per square feet.

Railroad Transfer Elevators.—The second class of elevators are the railroad transfer elevators. Some State legislatures have during the past few years passed acts compelling railroads to give hopper scale weights on transferred grain, and as a result a number of transfer houses have been built, handling from 100 to 300 cars per day. Their construction presents few difficulties, as they have no storage capacity whatever.

Two tracks run entirely through the building, the elevator machinery being placed in the platform space between the tracks. The cupola, with the elevator heads and scales, is located directly above the first floor, at a height to give sufficient fall, through car spouts, to trim or fill the cars without the use of manual labor in the cars.

Terminal Elevators.—The third class of elevators refers to terminal houses for storage, rapid handling and shipping, either by lake and rail or both. In general, these houses are termed "up houses," *i. e.*, they are entirely built on posts, in such manner as to form a large working floor

beneath the entire storage area. From three to four railroad tracks are run through the entire length of the house, and, according to the number of cars the house can unload simultaneously, they are termed 5-car, 8-car, 10-car houses, etc. The most modern construction locates all receiving and shipping elevators in one line, with receiving tracks on each side, thus occupying the three center bents of the elevator. The loading tracks are usually located in the outside bents, while, of course, the center tracks are arranged for shipping purposes. Owing to the size of the car, the transverse bents in the house are at least 13 to 14 ft. each, which makes the house either 56, 70, 84 or 98 ft. wide. Longitudinally the bents usually are in succession, 12, 12 and 14 ft., leaving the elevator legs at a distance of 38 ft. from centers. At the end of the elevator the power-house is located, in such manner that one of the loading tracks passing through the house also passes the engine-house, so that coal may be received from one end while grain is loaded into cars going in an opposite direction. All bin bottoms in a house of this description are hopper bottoms, and all bin openings of a diameter sufficient to fill elevator legs or conveyors to their full capacity.

A modern rapid-working terminal elevator is equipped with the very best machinery, electric lights, fire pump and service, passenger elevator, dust collectors and floor sweepers—in short, all contrivances that will cheapen or lessen labor and promote rapid handling of the grain. As the entire building rests on posts, the loads are concentrated at certain points. The load per pier varies from 300 to 450 tons, and as the safe bearing capacity of the soil seldom exceeds $2\frac{1}{2}$ to 3 tons, piling is resorted to, with cross and longitudinal oak grillage and stone piers. As the entire load of grain is thrown on the bin walls, the girders supporting these walls between the clusters of posts must be of a very strong construction, usually two 12×14 long-leaf yellow pine or oak sticks, on top of each other, supported by white oak corbels braced back into the posts below. Formerly the entire basement was taken up by stone piers and elevator tanks, but the tendency is now towards using less stone and extending the posts into the basement, leaving it open and concreted smoothly, so as to enable the removal of the dust and the admission of light below the first floor. Fireproof construction of the first floor and basement is much to be recommended, although it materially increases the cost of the elevator.

Cleaning Elevators.—Under the head of cleaning elevators we encounter the most complicated construction and the greatest variety of details. The writer will, however, confine himself to what has been adjudged the most improved arrangement.

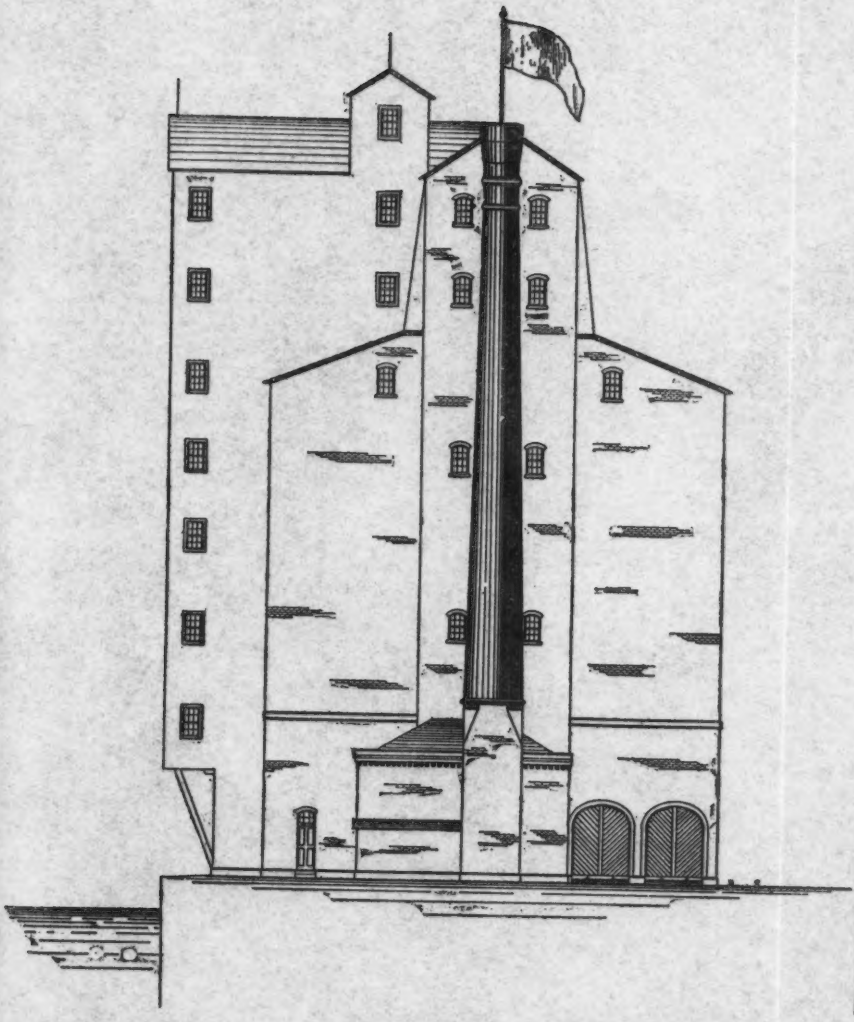
The receiving department of a first-class cleaning elevator is practically that of an up-house or handling house, as may be seen by referring to the accompanying sketch. Between the first and bin floors is, however, inserted a cleaning floor, a separate department with garners above and garners beneath. In this manner the grain from the scales is spouted into the garners; thence, by gravity, through the cleaners into the lower bins, whence it is elevated and spouted into storage, shipping bins or car spouts. By enabling a number of small bins overhead and below the cleaning floor to communicate with the cleaners, it can readily be seen that any mixing or grading can be done without difficulty.

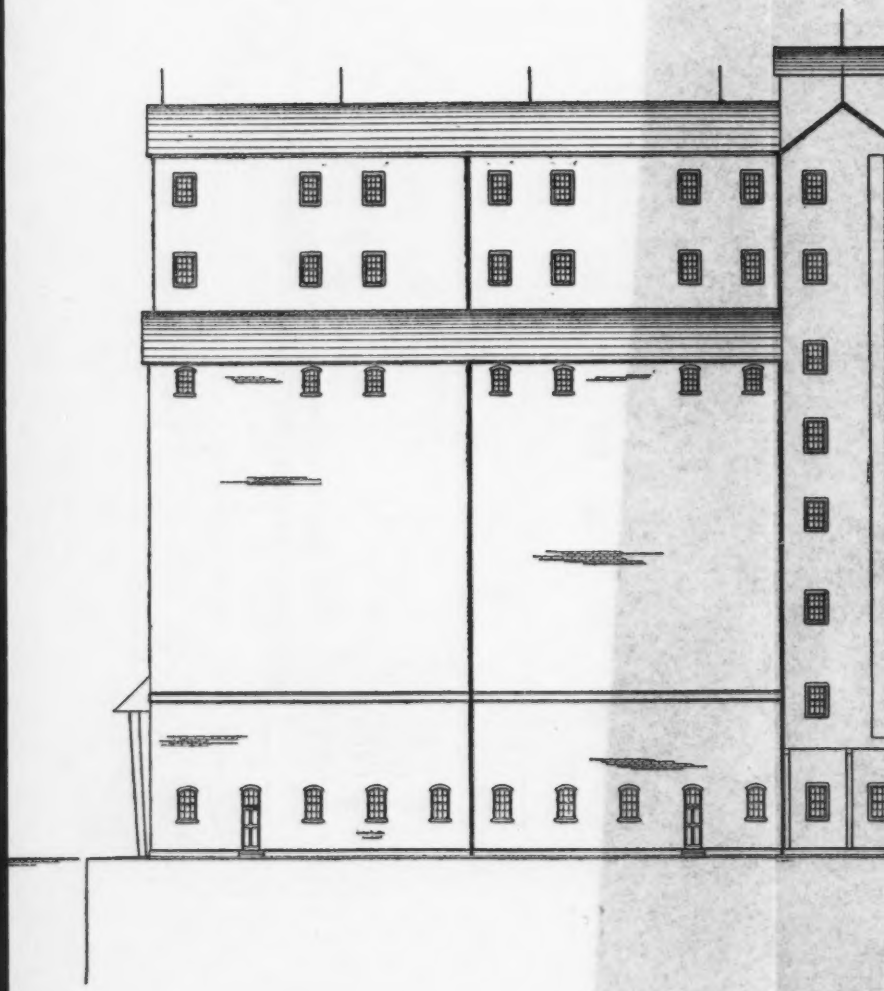
If cleaners are located on first floor or bin floor, elevator legs are required for either taking away from or supplying the cleaners, and as the capacity of a leg is 5,000 to 6,000 bushels per hour, while a cleaner only averages 2,000 and an oat-clipper 500 bushels, it is clear that there is a waste of machinery in this arrangement.

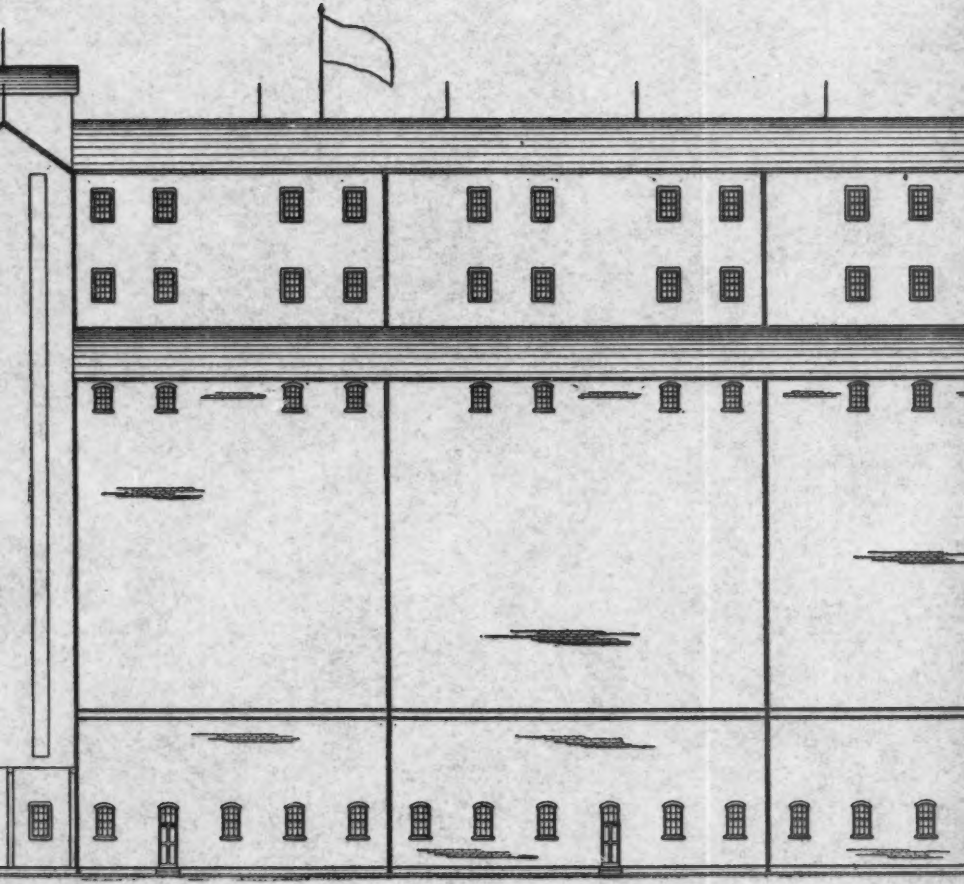
The dust from the cleaning machinery is blown into separators or cyclones, and exhausted by a powerful fan and blown into a large separator located directly above the boiler furnaces, where the dust and chaff form a material part of the fuel. The floor-sweepers before alluded to consist of 6-in. suction pipes extending to the floor, where a nozzle is attached, flat flared out, with a sliding gate. Any sweepings are brought in the vicinity of the nozzle, the gate is pulled out, and the sweepings are, a few seconds later, consumed in the boiler furnace.

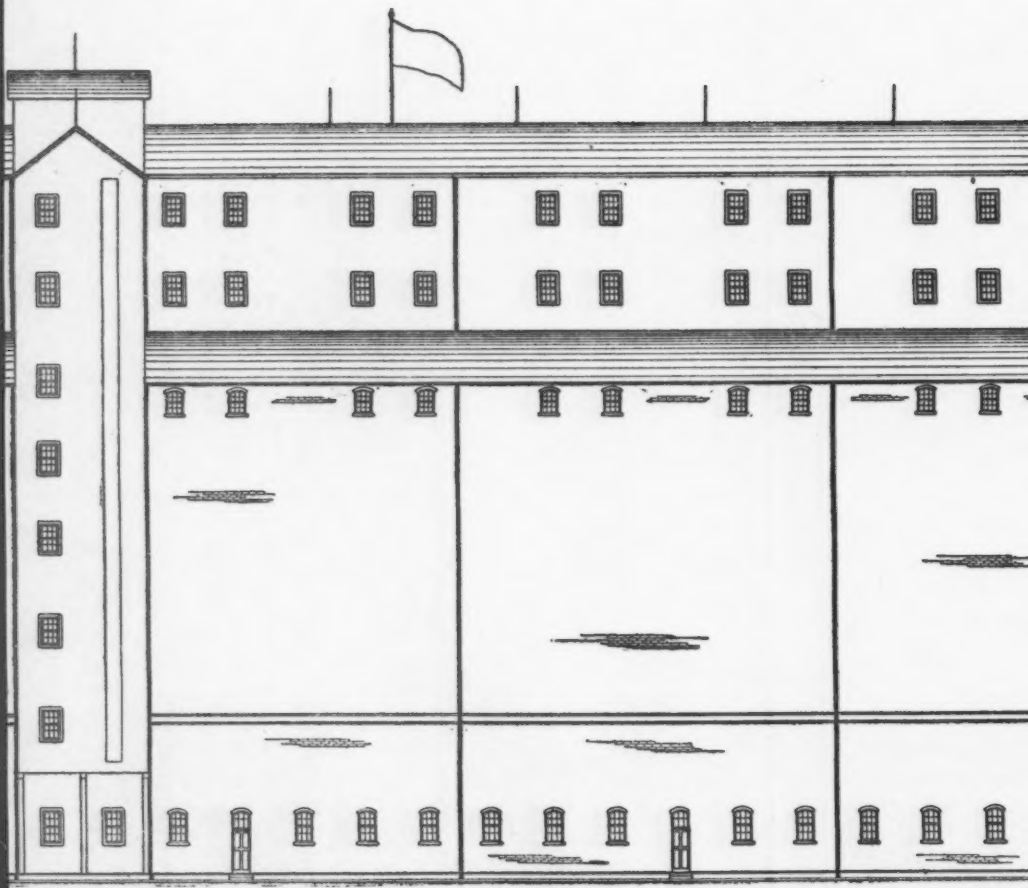
In a similar manner the dust from the elevator heads, garners and hoppers is disposed of. The surplus air from the fans in the cleaning machinery is thrown into a couple of large air conduits discharging above the cupola roof.

The storage of a cleaning elevator of this description consists of an annex, loaded and unloaded by means of belt conveyors. The annex should have hopper bottoms, and is shown in the accompanying plate built on ties, while the front or cleaning part is built on piles. Owing to a certain shrinkage in the planking, or cribbing, many difficulties are often met where an up-house joins a low annex, as while









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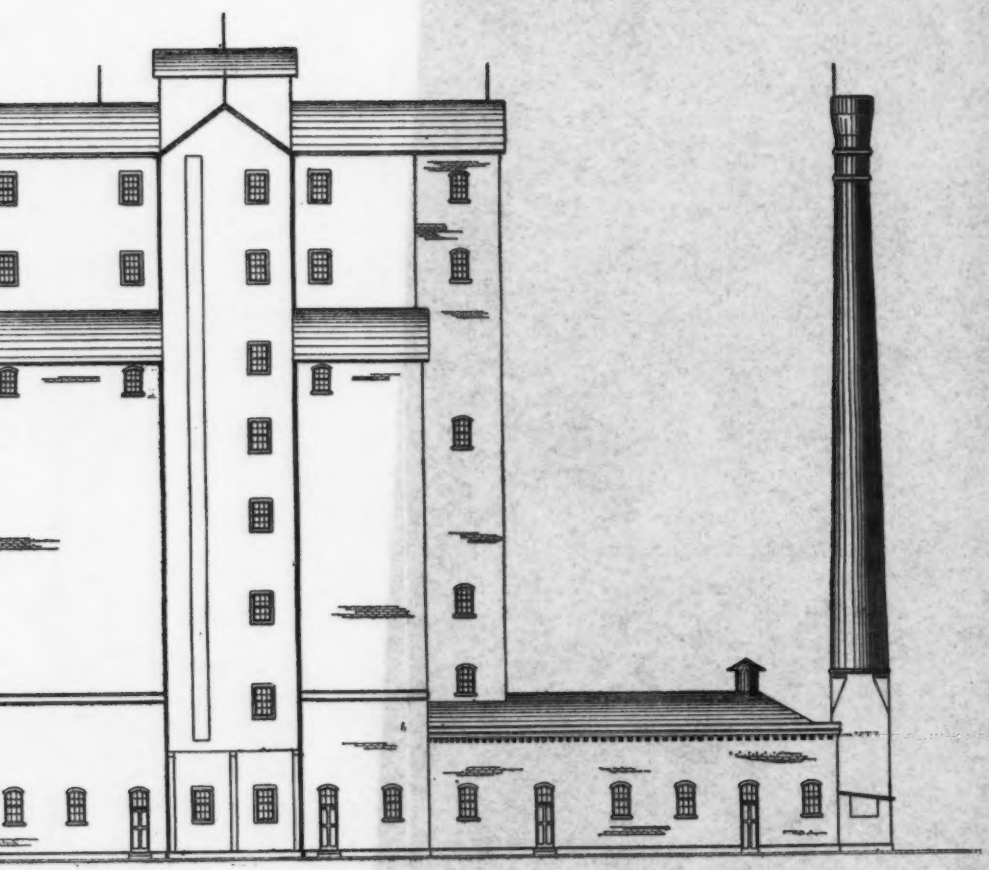
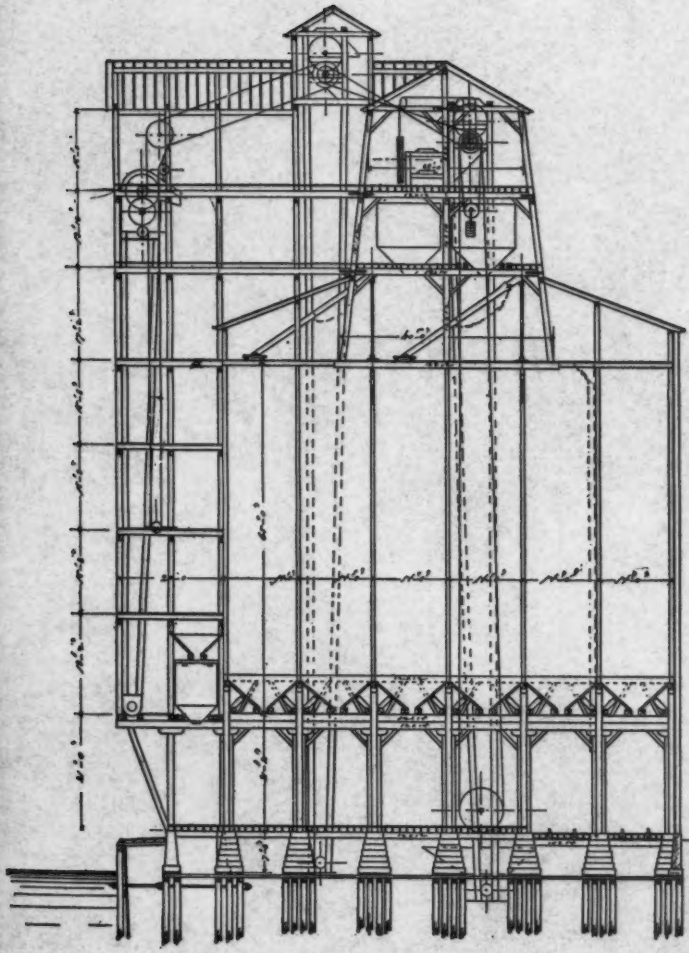
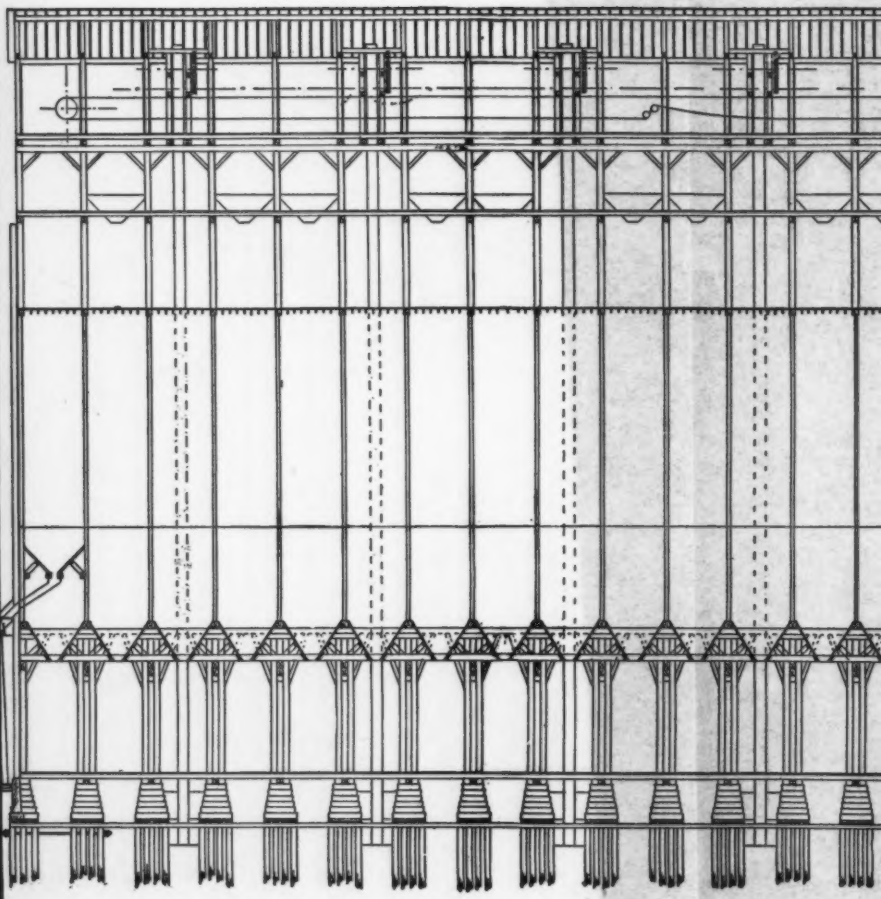
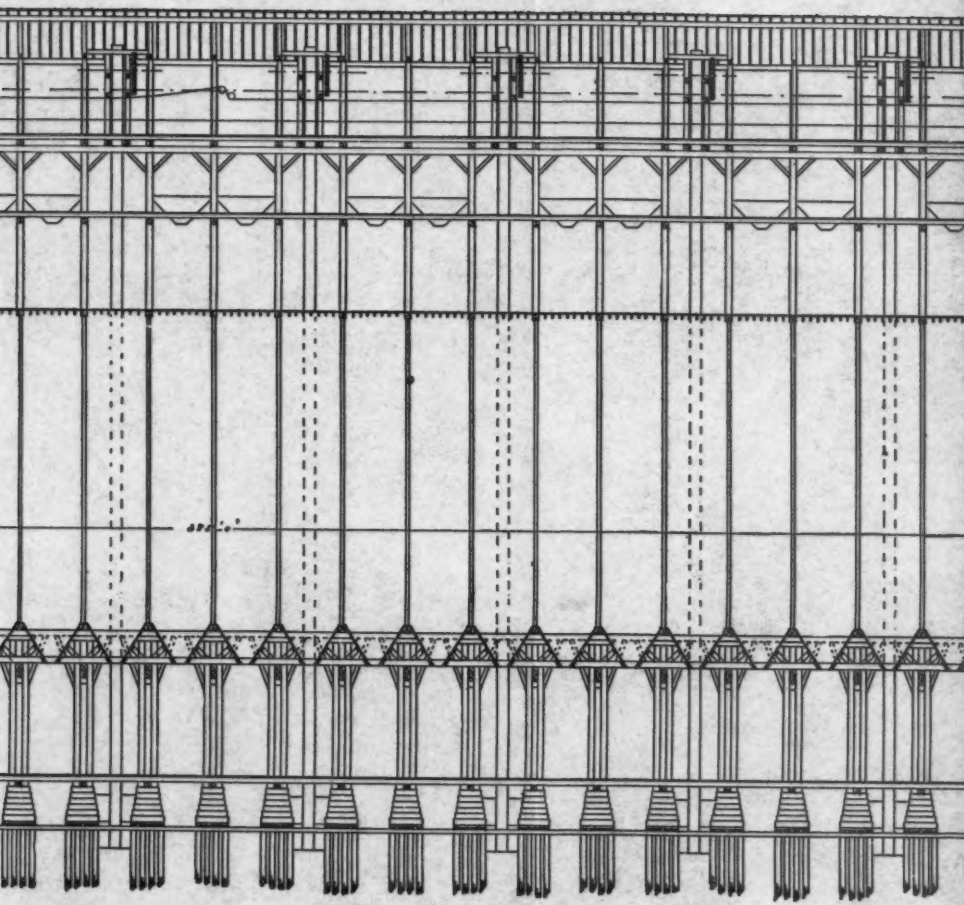
TRANS. AM. SOC. CIV. ENGRS.
HEIDENREICH ON AMERICAN GRAIN ELEVATORS.
PLATE I.



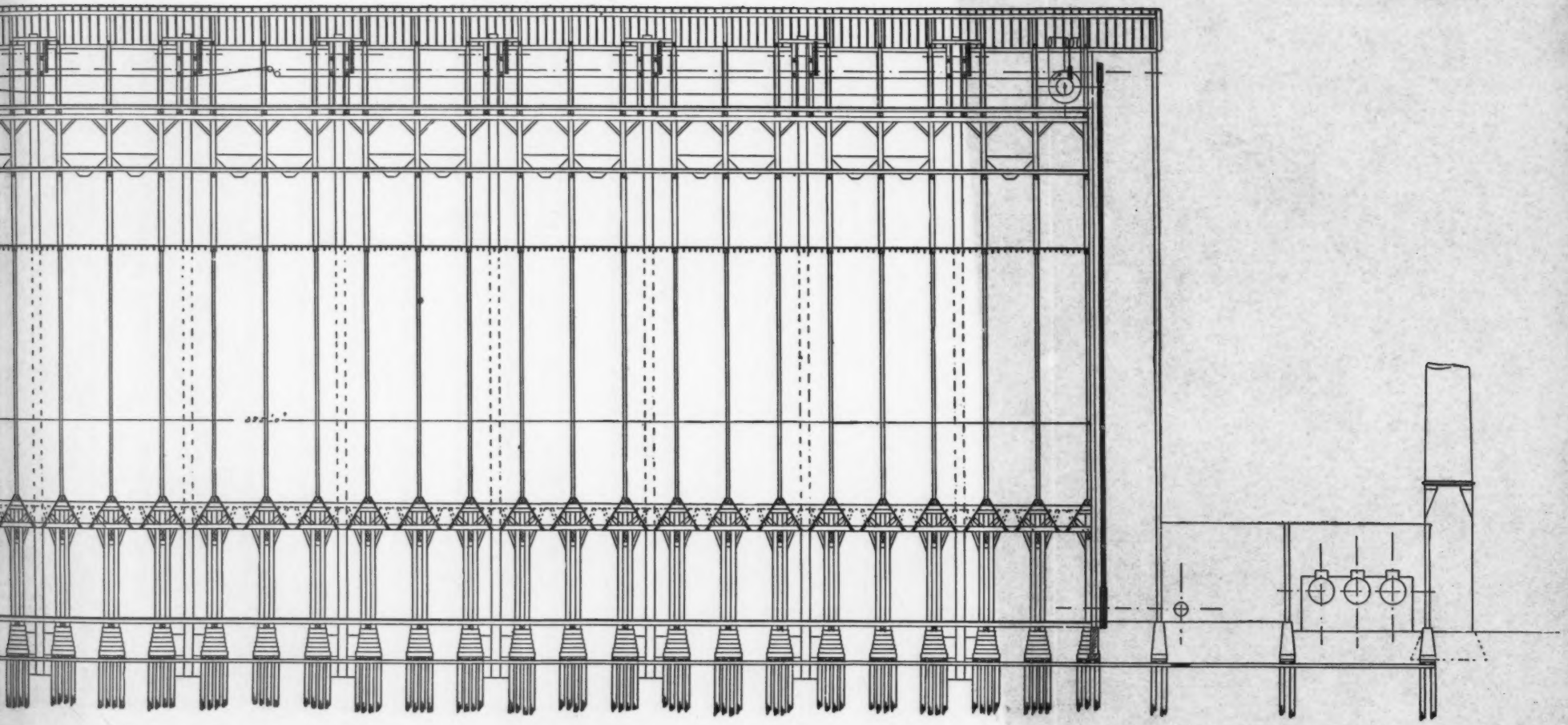


Cross Section.



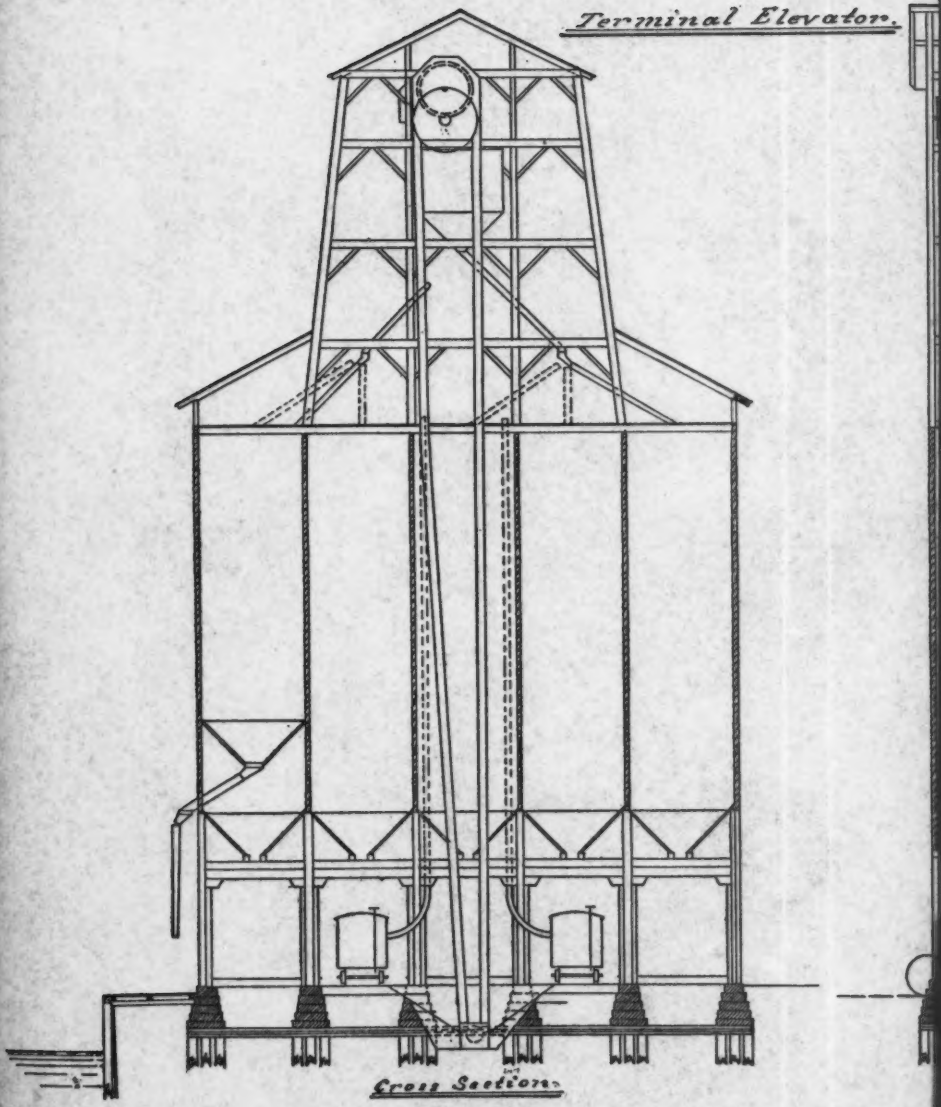


—Longitudinal Section.—



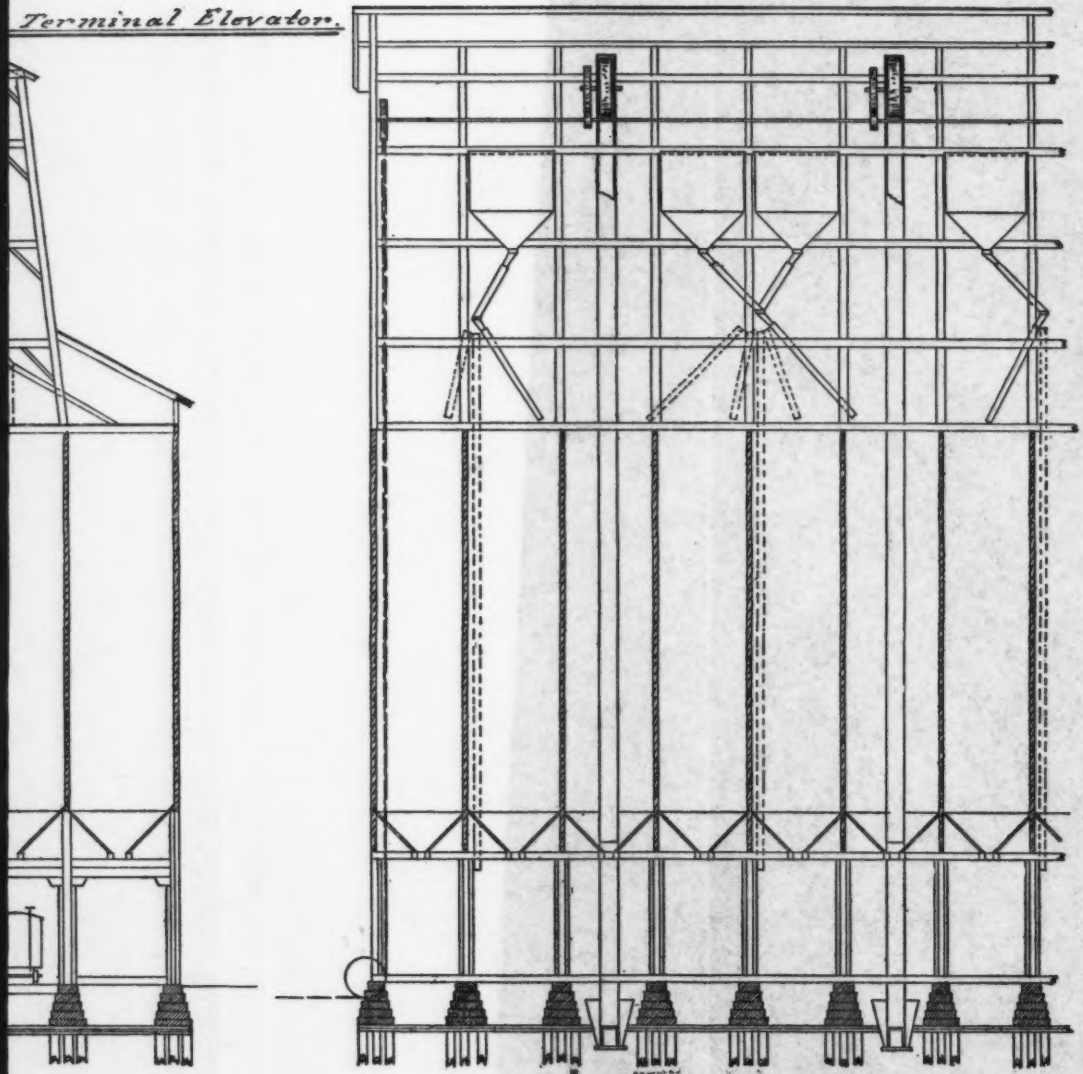
—Longitudinal Section.—

Terminal Elevator.



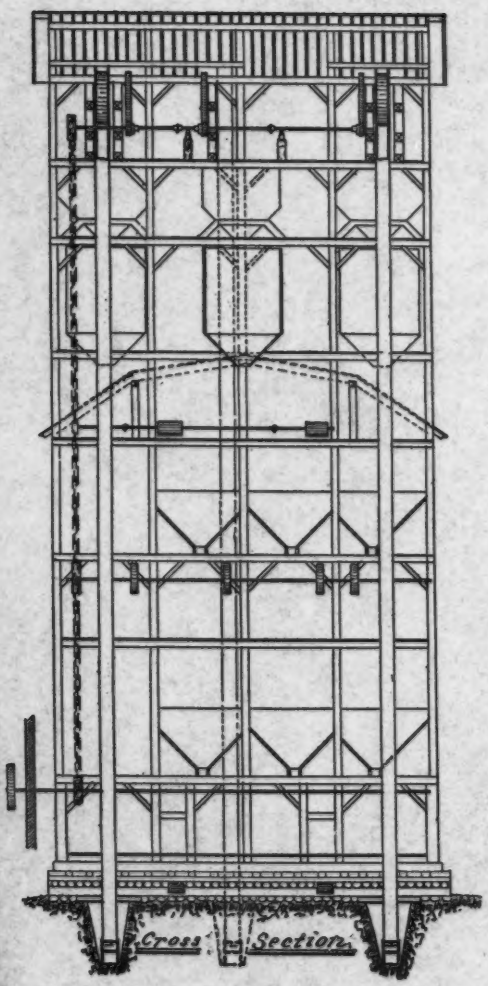
Cross Section.

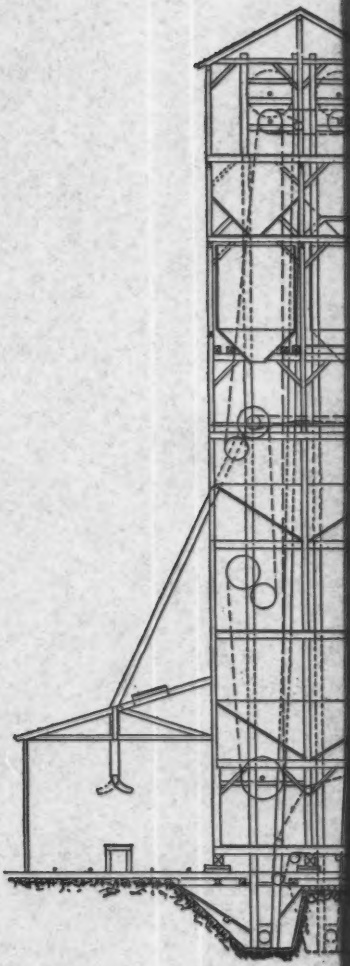
Terminal Elevator.



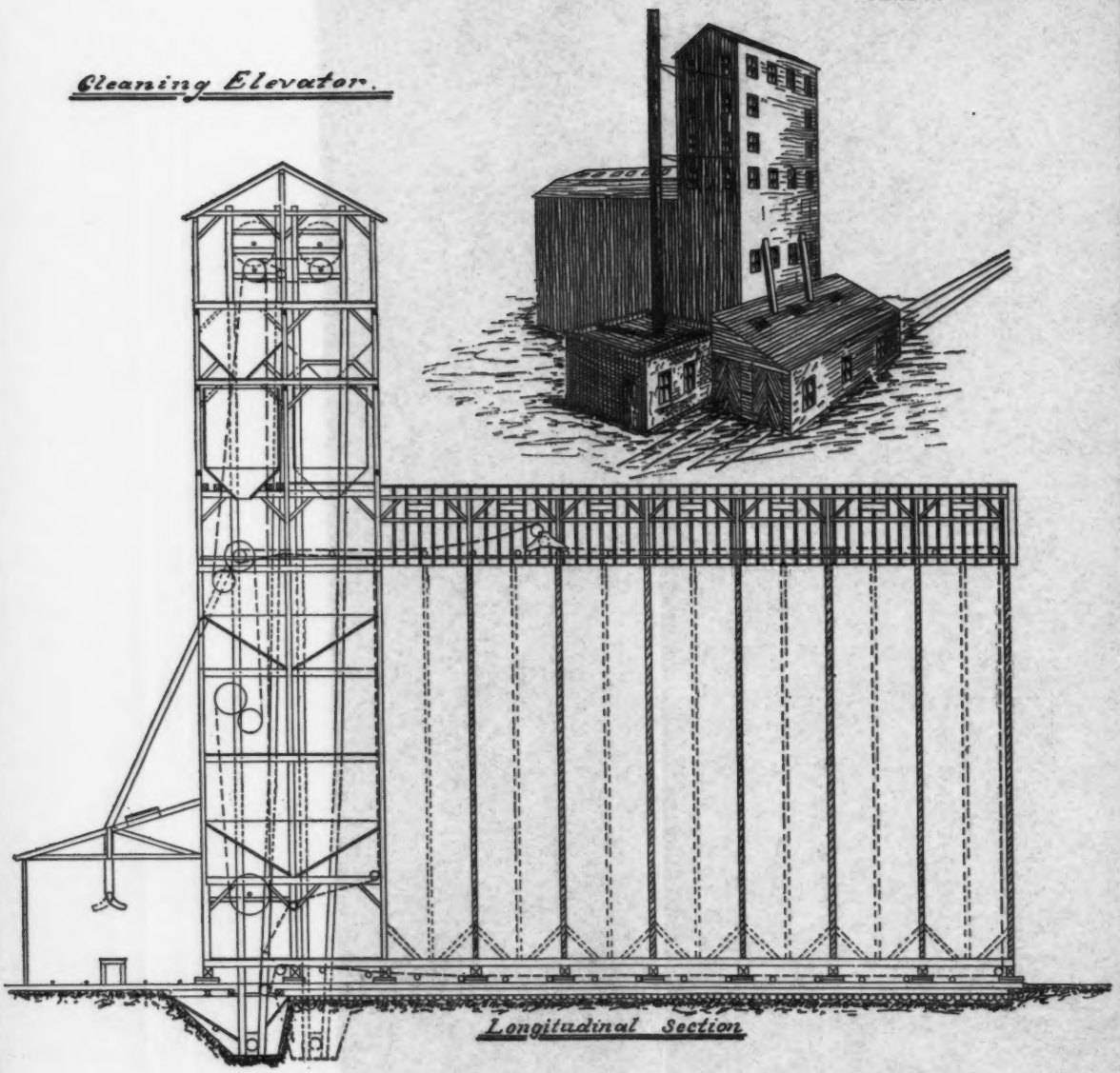
Longitudinal Section.

Cleaning Eleva





Cleaning Elevator.



Longitudinal Section

the posts in the former retain their length, the planking in the low annex shrinks several inches in the same height. This is usually remedied by giving the cross timbers running into the annex a corresponding camber, so that when the house has settled it will be nearly level.

Some builders erect the entire cupola of any elevator on independent posts extending through the bins, to counteract any influence of the shrinkage on the driving machinery, but the writer's experience is that the cribbing shrinks so evenly that no material trouble occurs on this score, so that he considers it advisable to build the cupola directly on the cribbing.

As to the driving machinery in grain elevators, it has changed materially during the past six or eight years. The most approved method to-day is a high-speed engine with manilla rope transmission from the engine to the last piece of machinery in the elevator. In a cleaning house the cleaner shaft should run about 250 revolutions per minute, as the cleaning machinery runs at a speed from 400 to 550 revolutions per minute, and the engine from 100 to 150 revolutions per minute. A direct rope transmission from a main-line shaft in the cupola to each of the elevator head pulleys is found to give satisfaction. The usual practice is to have eight strands of 1-in. rope for each transmission, the rope speed being only about 750 ft. per minute. It is very important that all the machinery in an elevator be strictly first class in every respect, as any hitch or slip in the driving gear is sure to cause serious chokings of the grain where it enters the elevator leg.

Grain elevators are usually covered with either brick or iron; in case of brick the unevenness in the settling between the exterior brick shell and the main structure is taken care of by means of anchors with slip joints, permitting the planking to go down 12 to 24 ins. without disturbing the tie between both parts. In case of corrugated iron covering, the sheets are put on with corrugations running vertically, and nailed 4 ins. from the lower edge only, so that the shrinkage of the planking is taken care of separately for each sheet.

The best roofs are probably the I. C. old process charcoal tin, although last year a large cleaning elevator was built with a roof of aluminum alloy metal, greatly reducing the weight and having the advantage of not requiring painting.

The principal requirements of a grain elevator, namely, strength, tightness, light, and effective and accessible machinery, are such as to invite the attention of engineers; and before closing the writer wishes to say that the handling and storing of grain, both in the Interior and at the lake and ocean terminals, presents a wide field for future discovery and improvements. Some of the immediate wants are: larger capacity cleaning machinery, adequate drying apparatus, automatic weighing machinery, fireproof bin construction, and pneumatic unloading of cars or vessels with a view of greater capacity per hour than can be obtained at present. And last, but not least, a general use of electricity for driving isolated parts of machinery, or, perhaps, for transmitting power to every piece of machinery in the entire elevator.

The main principles which must be kept in view while making these improvements are rapidity and economy of construction, and a reduction of the labor employed in the handling of grain in American grain elevators of the future.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

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(Vol. XXIX.—September, 1893.)

THE MANUFACTURE AND USE OF PAVING BRICK.

By DANIEL W. MEAD, Mem. Western Soc. Engrs., Assoc. M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The generic term brick includes within its meaning classes of material of such wide variations in their particular qualities as to need a more definite classification when considering the adaptability of such classes to particular purposes. Not all brick are qualified to withstand the high heat of the blast furnace which firebrick so well resist; neither are all brick suitable for the decorative work so well performed by enameled and pressed brick. So, when we consider a certain class of this material for street paving, it must not be confused with other classes manufactured for other purposes and perhaps entirely unfit for this particular use.

These manifold qualities of brick are due partially to methods of manufacture, but more largely to greatly diversified qualities of the clay from which the brick are made.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Occurrence and Distribution of Clays.—Clays may be classed as to their origin and occurrence as follows:

I.—Residuary clays result from the disintegration of rocks in place. The soluble and binding materials are leached out and washed away and leave the insoluble materials in a more or less divided form, as clay. This takes its character from the character of the rock from which it is derived, modified by the action of water. Some of the purest clays are derived in this way from feldspathic rocks from which the alkalies have been leached, leaving a clay closely resembling kaolin (pure clay). Other less pure clays are derived from the disintegration of limestone, sandstone, etc.; in each case, however, the soluble constituents are almost entirely gone, leaving the insoluble silicates, quartz grains, alumina and ferric oxide. Clays Nos. 1, 2 and 3 in Table No. 1 are examples of this class of clays.

TABLE No. 1.

	Residuary Clays.			Drift Clays.	
	From Limestone.		From Granite.		
	1.	2.	3.	4.	5.
SiO_2	71.13	49.59	78.83	40.22	48.81
Al_2O_3	12.50	18.64	13.43	8.47	7.54
Fe_2O_3	5.52	17.19	.74	2.83	2.53
FeO	.45	.27	....	.48	.65
TiO_2	.45	.28	....	.35	.45
P_2O_5	.02	.03	....	.05	.13
MnO	.04	.01	....	trace	.03
CaO	.85	.93	.64	15.65	11.83
MgO	.38	.73	.07	7.80	7.05
Na_2O	2.19	.80	.07	.84	.92
K_2O	1.69	.93	.37	2.36	2.60
H_2O	4.63	10.46	5.45	1.95	2.01
CO_2	.43	.30	....	18.76	15.47
C	.19	.34	....	.31	.38
SO_3	....	....	....	.13	.05

Nos. 1 and 2 are from the same vertical section, No. 1 being 4½ ft. from the surface, and No. 2, 8½ ft. from the surface and in contact with the underlying limestone. (Report of Director U. S. G. S., Vol. 6, p. 250. No. 3, see Wis. Geo. Survey, Vol. 2, p. 476.)

II.—Drift clays are the result of the mechanical action of the ice during the Glacial period, by which the various formations were ground up and mechanically transported and redeposited largely without the aid of water. These clays represent the character of the mother-rock much more accurately than those of Class I, as in this case the soluble matter is largely retained and not leached out, except by the action of the water, since their deposition. Of this class

Nos. 4 and 5 of Table No. 1 are drift clays from Milwaukee, Wis. (see U. S. G. S., 6th Annual Report, p. 280).

III.—Alluvial clays are residuary and drift clays rewrought and redeposited by fluvial agencies.

IV.—Indurated clays, or argilaceous rocks and shales, are formations resulting from the disintegration of the earlier rocks by various influences and their reformation into new strata. They have usually been subjected to great pressure from the superincumbent rocks, to which pressure they owe their physical character to a large extent.

Of these three classes, the residuary clays (Class I) are found wherever rocks and the result of their disintegration have been undisturbed by fluvial or drift influences, and are hence found largely outside the drift areas. The clays of Class II are found within the drift sheet and constitute the common brick clays of the Northern States (see Plate I). Those of Class III occur along the various river courses; while those of Class IV occur in the many geological horizons, which we may briefly summarize as follows, beginning with the oldest and lowest geological horizon. The clays occur in the Potsdam strata as shales interbedded with the sandstones.

In the Utica slate (sometimes considered the lower member of the Hudson River formation) as a dark carbonaceous clay slate, hard in Pennsylvania, soft in New York, sometimes interbedded with impure limestone.

In the Hudson River shale as shales and slates more or less interbedded with limestone (over 5 000 ft. thick in Pennsylvania and 200 ft. thick in Illinois).

In the Salina (or Onondaga salt group) as a red shale (in New York State, from 1 to 500 ft. thick).

In the Devonian as the Marcellus shales, a black slate, somewhat bituminous. As the Hamilton group, consisting of slates, shales and sandstones, 300 to 700 ft. thick; as the Genesee formation, the black slate of the West and South; as the Portage group, consisting of shales and flagstones; as the Chemung group, consisting of thin bedded shales, sandstones and flagstone.

In the Carboniferous, in which are developed the most extensive beds of fire clays, potters' clays, shales, soapstone, etc., interbedded with sandstone, limestone and coal (see map).

In the Triassic, which usually consists of dark sandstones, soft shales, and coarse conglomerates.

In the Cretaceous and Tertiary, which consists of earthy formations of sand and clays.

Of the deposits of clay above named, the clays from the Carboniferous period are most widely utilized for the manufacture of paving brick. At Columbus, O., the Devonian shales, or the product of their disintegration, is utilized, while at Syracuse the Salina shale is found available. Some few drift clays are also successfully used for the manufacture of a fair quality of paving brick, notably at Decatur, Jacksonville and Urbana in Illinois. A mixture of drift clay and carboniferous clay is utilized at Brazil, Ind., for the manufacture of paving brick.

The accompanying map shows the distribution of the carboniferous deposits east of the Rocky Mountains and also the outline of the drift area. It also shows the location of the principal paving brick factories and the principal cities which are now using this material for paving within the territory shown.

Character of Clay.—As may be judged from its wide occurrence and manifold compositions, clay varies widely in its extreme characters. But all materials to be classed as clays must have certain constituents in common. The essential ingredient is a hydrous silicate of alumina, known as kaolin, which, according to Professor G. H. Cook (see report on the Clay Deposits of New Jersey, 1878) is composed of—

Silica	46.3
Alumina	39.8
Water	13.9
	100.00

This may be considered a pure clay, and is rarely, if ever, found in Nature. To this is commonly added in varying quantities, silica, lime, magnesia, ferric oxide, potash and soda. The presence of these substances, which may be regarded as the impurities of clay, and the physical condition under which they exist, cause the wide variation in the clays themselves and to a great extent in the manufactured product made therefrom. There are also many other foreign constituents which are occasionally found in clays, but the above enter more largely and modify more widely the material as commonly obtained and utilized.

Character Due to Chemical Constitution.—Pure alumina will resist the highest temperature of the blast furnace, in which crystalline quartz

(silica) will be only slightly affected, both being practically infusible. Alumina shrinks, warps and cracks greatly in drying, but gives plasticity and adhesiveness to the clay and strength to the product. Silica prevents cracking and distorting, the more silica being present the less the shrinkage. But the more silica the less plasticity and adhesiveness of the clay and the less strength and greater brittleness. Lime and magnesia, while infusible in themselves or with alumina, fuse in the presence of an excess of silica, as do also several other common ingredients of clay, and form a "vitrified brick."

It is found that potash has the most active fluxing effect on clay, after which follows soda, lime, magnesia and iron, in the order named. To "vitrify," a clay should contain at least 3% potash, or 3½% of soda, or 5% of lime or magnesia, or 8% iron, or a combined proportion of any or all of these fluxes equal to these amounts. An appreciable less amount of these fluxing elements will leave the product more of the nature of a firebrick, unvitrified and porous, and, as a rule, unfit for paving purposes. A greater proportion than above specified is desirable, and will make the clay more easily vitrified at a less heat, and is to some extent a measure of its economic manufacture, as a lower heat and consequently less fuel will be required in its burning. Too great an amount of these fluxes, amounting, perhaps to three times the quantities above mentioned, will render the clay hard to handle on account of great fusibility. According to Richter, lime and magnesia are more active fluxing agents than potash and soda, but his conclusions do not agree with American experience. The presence of lime or magnesia in a paving brick in reasonable quantities is not believed by the writer to be detrimental to the brick if it exists in a finely divided state and is intimately commingled with the other constituents, so that a silicate of lime or magnesia will be formed in the burning. The Milwaukee building brick is one of the best of common brick, and it contains a large percentage of lime (see analysis Milwaukee clays, Tables Nos. 1 and 2), and Portland cement contains often as high as 60% of lime. In each case, however, the lime exists in close chemical or physical union with the other elements of the material.

Iron in considerable quantities has a fluxing effect with silica and to this extent cements it together and gives it strength. It is not the most valuable of constituents in this regard however, and its presence

is not essential to a first-class paving brick. Iron, when present, is usually in the form of hydrous peroxide or protoxide of a yellowish or bluish color. During the burning, the water of crystallization is expelled and the iron takes the form of the red peroxide, giving its color to the material in proportion to the amount present.

The presence of lime, however, affects this result as when this occurs a compound silicate of lime and iron is formed which is white or cream in color. A black color in brick is usually due to the presence of organic matter in the clay.

Potash and soda fuse at a lower temperature than the other constituents of clay, and their presence in suitable quantities is desirable for the manufacture of vitrified paving brick.

In Table No. 2 the analyses of various paving brick clays are given with that of some other noted clays for comparison. These analyses have been compiled from a variety of sources, too numerous to be mentioned in detail.

Character Due to Physical Condition.—The influence of physical condition is equally important to that of chemical character. Many of the clays from the older formations have been compressed and consolidated and form slates and other hard argillaceous rocks; others less compact form the shales, while others exist in a plastic form. There is a marked difference in their adaptability for manufacturing use under these varying conditions, and the methods of manufacture must be largely determined by them. If a clay is not found naturally in a plastic condition, it must be reduced to a finely divided state by mechanical means before it can be tempered and made into paving brick. While as previously noted, the fusing of clay depends on its constituents to a great extent, yet its physical condition also modifies this quality largely. Coarse clay, even with considerable of the fluxing materials, will resist considerable heat. The more finely clay is ground, the more easily it is vitrified and the tougher, stronger and more impervious its produce becomes. Fineness in grain is an essential feature of the best paving clays.

The ingredients of the clay exist in various forms which affect the clay and its product. The uncombined silica may be more or less finely divided and its condition has its effects on the action of the fluxes. In clays derived from feldspathic or micaceous rocks, undecomposed feldspars and micas sometimes occur. Lime, instead of being

TABLE No. 2.

Analysis of Paving-Brick Clay.

	Silica.	Alumina.	Perox. of Iron.	Protox. of Iron.	Lime.	Magnesia.	Potash.	Soda.	Water and Loss.	Undetermined.	Total.	Geological Source of Clay.
Kaolin	46.30	39 80	.....	.....	.....	.....	.....	.....	13.90	.....	100.00	Pure clay.
Stonebridge, Eng	67.34	23.03	.....	2.03	.....	.....	1.38	1.38	8.24	.....	102.02	Fire clay.
Mt. Savage, Md., non-plastic	50.46	35.90	.....	1.50	0.13	0.02	*Nil.*	*Nil.*	12.74	Mang. Oxide trace.	100.75	" "
Milwaukee (white brick)	38.22	9.75	2.84	1.16	3.24	15.83	2.16	0.65	2.80	Carbonate of lime. 23.20	99.85	Drift clay.
Philipsburg, N. J.	56.78	17.38	6.50	Phosphorus, 0.133	4.14	3.15	and organic matter, 3.427	3.427	and carbonic acid. 7.600	Sulphur, 0.89	99.910	
Syracuse, N. Y	67.67	11.67	6.53	.....	12.74	0.95	0.80	0.80	.....	.....	100.36	Salina shale.
Cumberland, W. Va	69.02	22.07	4 53	.....	1.70	0.38	1.34	1.34	.....	0.96	100.00	Carboniferous.
New Brighton, Pa	67.36	22.05	5.61	.....	0.86	0.36	2.70	2.70	.....	1.06	100.00	"
Canton, O	67.65	18.36	8.34	.....	0.80	1.02	2.58	2.58	.....	1.25	100.00	"
New Lisbon, O	64.08	25.32	5.44	.....	0.30	0 29	0.63	0 63	.....	3.94	100.00	"
Middleport, O	71.57	17.06	8.34	.....	0.50	0.58	0.56	0.56	.....	1.39	100.00	"
Brazil, Ind	77.67	14.77	3.63	.....	0.38	0.27	2 43	2.43	.....	0.85	100.00	" and drift.
Columbus, O	66.30	18.62	9.78	.....	0.40	0.84	1.89	1.89	.....	2.17	100.00	Devonian shale.
Akron, O	60.05	20.00	6.82	.....	0.52	0.45	1.79	1.60	1.95	Sulphur, 1.95	101.11	Carboniferous.
Haydensville, O	72.24	16.87	Iron 0.16	.....	0.50	trace	1.09	1.09	5.14	.....	100.00	"
Zanesville, O	61.80	20.76	8.70	.....	1.38	1.09	1.44	1 44	.....	4.83	100.00	"
Robbins, Tenn	70.57	15.19	7.97	.....	0.78	0 32	1.15	1.15	.....	4.02	100.00	
Rock Island, Ill	60 64	22.84	6.10	.....	0.24	0.75	3.28	0.57	5.00	.....	99.42	Carboniferous.
Galesburg, Ill	68.69	17.95	7.25	.....	0.76	1.47	2.83	2.83	.....	1.05	100.00	"
Ottawa, Ill	52.26	33.47	.....	4.51	3.01	2.91	1.10	1.10	2.74	.....	100.00	"
Clinton, Iowa	75.50	13.04	Iron 4 00	.....	0.50	.....	4.50	.....	3.00	.....	100.90	Hudson River shale.
Burlington, Ia	77.40	11.74	3.29	.....	1.60	1.91	3.76	0.47	.....	.....	100.17	Carboniferous.
Bloomington. Ill	67.80	11.55	4.31	.....	8.90	5.32	2.62	2.62	.....	.....	100.00	Drift clay.
Ft. Smith, Ark	57.10	23.74	8.18	.....	0.53	1.04	1.53	0.87	7.21	.....	.....	Carboniferous.
Kansas City, Mo	64.37	19.73	9.07	.....	0.82	2.32	1.89	1.89	.....	1.80	100.00	"
Leavenworth, Kan	58.45	21.96	Iron 8.43	.....	1.05	1.57	2.00	2.00	6.51	.....	99.94	"

finely divided, may occur as lumps or pebbles, in which condition it will unite with the other ingredients only on its surface, the balance burning into caustic lime, which on exposure will gather moisture and slack, disintegrating and crumbling the brick.

In general, a clay which will not readily melt and run, and yet one which will fuse and vitrify, but keep its shape, is essential to the manufacture of the best paving brick. Analysis and physical examination will point out the probability of the development of certain characteristics in the manufactured product, but, after all is done, the only thorough test is the working of the clay by suitable methods and its proper burning.

Mining.—The methods of mining clays depend entirely on their manner of occurrence and physical condition. With the softer clays, lying in beds which may be mined from bluffs or in open pits, the steam shovel may be used to excavate and deposit them in cars which is the cheapest method of handling large quantities of clay. With the harder clays the same method of loading may be utilized, but the clays must first be loosened by powder or dynamite. When a steam shovel is not used, wheel or drag scrapers may be utilized for short distances, or carts and wagons filled by shovelers may be used where the haul is longer. Winding drums with automatic dump cars, running by gravity to the pit, are popular in open-pit mining, and cars with horse-power are used in pit, drift or shaft mining. The various forms of electric motors and wire-rope tramways may also be utilized for the transportation of clays from pit to factory; all depending on the relative location and conditions governing the same.

The Manufacture of Brick.—The greatest diversity, both in the mechanical and chemical constitution of clays, renders the question of method of manufacture a difficult one, and a new factory, using a new and untried clay, is always more or less experimental; for the knowledge of the successful utilization of one clay is not wholly applicable to another.

All clays are improved by being loosely thrown up and exposed to the action of sun, rain and frost, all of which tend to disintegrate and make them more readily workable. Some clays are improved by thoroughly wetting and allowing them to lie in this condition for a day or more. This, to some extent, takes the place of weathering. The nearer homogeneous and fine grained a clay naturally occurs, the fewer processes necessary in handling it.

Soft, homogeneous clay may be run through rollers, to crush the lumps, and from the crusher it may go directly to the brick machine, although it is usually desirable to run it first through a pug mill for proper tempering. Lumpy clay of medium hardness can be pulverized by the granulator, but the indurated clays, shales, etc., are best treated by the dry or wet pan, the former being usually the most available for the rapid manufacture of large quantities of brick.

Indurated clay, when pulverized by one of the methods mentioned, is greatly improved by being tempered, or "pugged," 24 hours or more, before being used in the brick machine, although this is not usually done in the manufacture of paving brick. It should always, however, be reduced to an impalpable powder and thoroughly mixed with water before being molded into brick.

The common method of making building brick is by what is called the soft-mud process, in which the simplest of brick-making machinery is used. This is used only to a very limited extent in the manufacture of paving brick, Bloomington, Ill., being the only place familiar to the writer where this process is still used.

The dry-press process of brick manufacture has not as yet come widely into use for the manufacture of paving brick, although certain clays might be worked by this method. As a rule, however, a dry press does not bring the materials of the brick into such close union as is done by tempering with water. To be readily vitrified, a clay must contain a larger percentage of fluxing materials to be suitable for manufacture by this process. The writer understands that some paving brick are being made at Middleport, O., and Louisville, Ky., by this method, although he has not seen them.

What is known as the stiff-mud process is the one usually adopted for the manufacture of paving brick and seems to be the best adapted for the present circumstances of its manufacture.

The clay, if indurated, is first reduced to a powder, usually by means of the granulator or dry pan, and then thoroughly tempered in a suitable pug mill before passing to the brick machine. As a rule, the longer and more thoroughly the clay is worked or tempered, the more uniform and better will be the resulting product.

The auger machine has given the best satisfaction in the manufacture of stiff mud brick. Other systems have been tried, but they have been quite generally abandoned, and the machine-makers of the United States have adopted this type of machine almost universally.

On leaving the machine, the brick manufactured by this process are dry enough to handle, and they are placed on trucks or cars and conveyed at once to the dry house, unless the brick are to be re-pressed. After leaving the brick machine, some makers re-press their brick before drying. This forms them into more symmetrical shape and to a certain extent compresses them and aids in the removal of laminations. There is no doubt that the brick is somewhat improved by re-pressing, and it adds much to the appearance of the finished pavement, but it is not in general use at present. Many factories, however, furnish both common and re-pressed paving brick.

Drying.—Several systems of drying are in successful use among the paving-brick manufacturers. First, by a hot floor, which may be produced by furnaces or steam pipes under the floor over which the brick are hacked to dry. Second, by slatted floors under which are steam-piping and over which the brick are hacked to dry. Sometimes a modification of this method is used in which the dry house has racks from floor to ceiling on which the brick are placed for drying. The third system consists of a series of flues or tunnels into which the brick are run on cars, which will hold about 500 brick each. These tunnels are heated by means of furnaces or steam pipes. In all cases it is necessary to provide for a change of air as fast as the air in the dry house becomes saturated. The third method in one of its various forms seems best adapted for handling large quantities of brick, as the brick can usually be dried in from 18 to 36 hours by this method, where it takes from one to five days on the dry floor and from five to ten days if dried in racks. The saving in time and cost of handling by the use of the tunnel system is considerable, as the brick are placed directly on the cars from the brick machine, or re-press, and are not handled again until the car is run into the kiln with the dry brick ready to set. Any of the above methods of drying places the manufacture of brick independent of the weather.

Outdoor drying is a method too slow and uncertain for practical use in handling large quantities of brick. It is used, however, in many factories for the manufacture of building brick and may be used in small paving brick factories, for summer runs. A covered rack system is the best when outdoor drying is to be attempted.

Clays vary greatly in the facilities with which they may be dried. Clays highly aluminous must be dried with great care and often very

slowly, otherwise they warp and crack, while those with much silica will stand forced drying. Hence, the method of drying must be selected and so modified as to suit the clay used. Thorough drying greatly facilities the burning of the brick.

Burning.—There are two methods used for burning brick. The ordinary way in which common building brick are burned is in the up-draft or clamp kiln. This furnishes good ordinary brick, but it is difficult to raise the heat high enough to procure a large percentage of brick fit for paving purposes. It is almost impossible in this class of kilns to get a uniform product, the arch brick being very hard and the top brick poorly burned. Not over 40% of the brick in a kiln is available for "pavers." The consequence is that very few up-draft kilns are used for the manufacture of paving brick.

In up-draft kilns the fires are built in arches formed at the bottom of the pile of brick to be burned, by the method of setting the brick themselves. The heat rises through the spaces between the brick by the natural draft, which is regulated by a plaiting of brick laid flatwise and close together on top of the kiln. The brick in this plaiting may be set on edge, leaving a space of 2 ins. between brick when more draft is desired. In this manner the draft can be forced to such portion of the kilns as is necessary.

The down-draft kiln secures a uniform and much higher temperature, a large percentage of the brick, from 80 to 90% in a well-designed and well-constructed kiln, being suitable for paving purposes.

These kilns are built in the form of square, oblong or circular brick ovens, having fire pockets or furnaces built in their outer walls, at uniform distances about their circumference. The bottoms of the kilns are perforated more or less, to allow the gases to pass through the flues which are beneath the floor, and which lead to the chimney. The fire passes up from the furnaces into the kilns, then down through the brick to be burned to the flues, and thence to the chimneys. The draft in these kilns is much greater and can be better regulated, and as the brick are all inclosed within the kiln walls and roof, there is not the chance for the cooling of the outer brick as in the clamp kiln; hence, a more uniform and higher heat is possible. In either style of kiln, coal, oil or wood may be used as fuel, but the furnace should be constructed with due regard to the fuel to be used.

In burning brick, the fires must be started slowly in order to

"water-smoke" the brick without cracking them. In the brick, as they come from the machine, there is from 20 to 30% of water; about 50% of this water is the water of the pores, and is removed at a temperature of 100° Cent. (212° Fahr.). In the drying the balance is lost at a temperature of about 760° Cent. (1 400° Fahr.) in the burning. The former is sometimes called the water of the pores, the latter the water of composition. There is usually more or less water of the pores left in the brick after drying, although it is important to avoid this as far as possible. The loss of the physical and chemical water of the brick is accompanied by a corresponding loss in weight, and a considerable shrinkage in the dimensions of the brick. The final vitrification of the brick is a change in physical form, not in chemical composition, and consequently a change in dimension but not in weight may be noted.

The following is the record of the various weights and dimensions of one make of paving brick, which is in successful use in a number of cities, during the different periods of its manufacture:

TABLE No. 3.

SHOWING VARIOUS WEIGHTS AND DIMENSIONS OF BRICK DURING DIFFERENT STAGES OF MANUFACTURE.

Average of 12 samples.

	On leaving machine.	On leaving dryer.	Burned, not vitrified.	Vitrified.
Weight	6.46 lbs.	5.79 lbs.	5.08 lbs.	5.08 lbs.
Length	$8\frac{1}{2}$ ins.	8 ins.	$7\frac{7}{8}$ ins.	$7\frac{7}{8}$ ins.
Breadth	$4\frac{7}{16}$ "	$4\frac{3}{16}$ "	$3\frac{7}{8}$ "	$3\frac{7}{8}$ "
Thickness	$2\frac{1}{4}$ "	$2\frac{1}{8}$ "	$2\frac{1}{8}$ "	2 "

Slow firing is continued until the smoke passing off shows no further signs of the water-smoke (steam), after which the fires are gradually raised until the temperature throughout the kiln is sufficient to vitrify the brick, at which point it is held until they reach the proper point of vitrification, which is shown by the trial pieces or whole brick taken out through inspection holes in the top and sides of the kiln. After this, the kiln is gradually cooled down and the brick removed. Too rapid cooling is detrimental, as the brick are rendered very brittle. By slow cooling the brick are annealed and rendered tough. The burn-

ing occupies from two to four days for water-smoking, from four to six days for burning proper, and from three to five days for cooling.

Table No. 4 gives some details of the methods of manufacture as used at different paving brick factories in the United States.

Qualities of Paving Brick.—In all lines of practical work, experience with a given material is the only satisfactory method of determining the value of its various qualities. The individual and characteristic lines of the human face cannot be specified, and yet by them a friend is recognized and character is largely shown. In the same way it is difficult, if not impossible, to specify the limits of the qualities of brick necessary for paving purposes. As in the case of cement, stone and wood, paving brick must be selected with due reference to the uses to which they are to be put; that is to say, to the nature and extent of the traffic they are to encounter and the character of the climate they are to withstand. A large percentage of clays are undoubtedly capable of producing brick suitable for country roads, light suburban travel and residence streets of towns and cities. From many can be made brick which will withstand the moderate traffic of the smaller cities of from 30 000 to 50 000 inhabitants. It is the writer's belief that clays can be found which, if properly manufactured and properly placed in the pavement, will out-rival granite under the heaviest traffic, and some brick are now made which it is believed would prove economical under such traffic.

The color in a brick is no criterion of its value as a paving brick when comparing brick of various makes; but, in inspecting brick from a single factory, the color will usually furnish a fairly safe guide as to the relative hardness, when the inspector is thoroughly acquainted with the particular manufacture. The knowledge gained regarding the relation of color and quality in inspecting one make of brick, however, can seldom be used in that of another make from a different locality. The brick vary in color according to the amount of burning. As a rule, the depth of color increases with the increased burning. This is true only where the brick are not salt glazed, which should never be allowed in those for paving purposes.

Another criterion as to the character of any single make of brick is the comparative size. As is seen in Table No. 3, the harder a brick is burned, the smaller it becomes up to a certain limit which must be determined for each make of brick. Hence, in the inspection, the un-

TABLE No. 4.

Showing Methods of Manufacturing Paving Brick.

Locality.	Kind of Clay.	Geological Origin.	Methods of Manufacture.	Method of Drying.	Character of Kilns.
Brazil, Ind.	Fire clay and surface clay mixed.	Carboniferous and drift.	Dry pan. Pug mill. Stiff mud machine.	On slat floor.	Down draft.
Decatur, Ill.	Surface clay.	Drift period.	Roller crusher Stiff mud machine.	On rack in steam-heated dry house.	Down draft.
Bloomington, Ill	Surface clay.	Drift period.	Vertical pug mill. Soft mud machine.	In yard.	Up draft.
Galesburg, Ill.	Shale clay.	Carboniferous.	Dry pan. Pug mill. Stiff mud machine.	On cars in drying tunnels.	Square down draft.
Galesburg, Ill.	Shale clay.	Carboniferous.	Dry pan. Pug mill. Stiff mud machine.	On hot floor heated by furnaces below.	Round and square down draft.
Evansville, Ind.	Shale clay.	Carboniferous.	Dry pan. Mixer. Pug mill. Stiff mud machine.	Tunnel dryer.	Square down draft.
Rock Island, Ill.	Shale clay.	Carboniferous.	Dry pan. Screen. Pug mill. Stiff mud machine.	Tunnel dryer.	Round down draft.

duly large brick may be unhesitatingly rejected as too soft. As in the manufacture of brick, the die constantly wears larger and must be replaced occasionally by a new one, a change in size from this cause must not be confused with that due to under-burning.

In general, a brick for paving purposes must be homogeneous, free from uncrushed or lumpy material, especially if such material is not united by vitrifaction with the balance of the material of the brick. Vitrifaction is desirable, but not essential, as many paving brick, especially those made in West Virginia, cannot be classed under this head. These are made from clays very near fire clays in character and are giving very good satisfaction, at least under moderate traffic. "Vitrified firebrick" is a misnomer, as fire clays are so named on account of their withstanding high heats without vitrifaction.

In this country, the climate in which the majority of paving brick is used is so severe that the disintegrating effects of frost are the most severe test a paving brick must stand, especially in streets of moderate traffic. Hence, one of the first requisites of such a brick must be that it will not absorb a large percentage of water, for if it should, as has been shown by experience, the freezing of the absorbed water will cause rapid crumbling. The permissible ratio of absorption cannot be definitely fixed at any given percentage, for it is found that this ratio varies with different classes of brick. One class of brick, which seems to be uniformly made from clays which approach near to fire clays in character, will admit 4 or 5% of water and still not crumble through the action of frost; while others, if not burned hard enough to render them impervious to more than 2½ to 3%, will be rapidly disintegrated by the frost.

With the auger machine, if the clay is not properly tempered, a core or lamination is produced in the brick which prevents proper cohesion of the material and affords a seam where the frost may enter. It is inadmissible in paving brick. Fire cracks, caused by too rapid firing, if small and superficial, are not of much importance, but they should be limited in number and extent.

The presence of lime, in itself, as has been before stated, is not detrimental if in limited quantities, yet this must not exist as lime pebbles or it will render the product entirely unfit for use by disintegrating and crumbling it.

The specific gravity of a brick is somewhat of an index of its com-

parative value, as the more material contained in it, the greater its density, and other things being equal, the greater its resistance to abrasion, crushing, etc. A certain amount of toughness is desirable in a paving brick, to prevent splintering and breaking under traffic. This quality, the writer believes, is at present overestimated, as when laid in the street a brick can splinter only to a limited extent at the corners after which the shape assumed is such as to greatly resist abrasion.

The brick must be of sufficient transverse and crushing strength to resist all the demands of traffic with a sufficient factor of safety. Further than this, these qualities are of little material value, although their great development, together with other qualities in equal degrees, is evidence of high perfection in the class and manufacture of the brick.

Testing the Material.—In making tests for relative qualities of brick, nothing will take the place of experience. A few general suggestions, however, for making ready tests, such as are now in use, are offered with the hope that they may prove serviceable.

The personal error is so large in the testing of material that no attempt should be made to compare the results obtained by an inspector unfamiliar with the methods and results of making such tests, with the published tests of experienced observers. Instead, however, standard makes of brick should be tested in connection with samples submitted, by means of which results may be checked and a comparative relation established with other experiments.

Prof. I. O. Baker has pointed out the wide variation obtained in the crushing strength of brick. He obtained a strength of from 7 000 to 9 000 lbs. per square inch, with ordinary care in the preparation of the surfaces of the material to be tested, and with the same material, with beds more carefully prepared, strengths ranging from 16 000 to 21 000 lbs. were obtained. The variation in strengths shown by testing quarters, halves, three-quarters and whole brick, or brick on side, edge and end, has also been shown by Prof. Baker to be fully as great. It is desirable that a uniform method of testing be established as far as possible in order to allow a comparison of results. The test for crushing strength is believed by the writer to be of little or no value unless in comparison of the values of high-grade paving brick. The test is difficult of application, requiring expensive machinery; and unless carefully made by skilled observers, under definite given conditions, the results are very

uncertain and unreliable. The transverse strength can be determined with greater accuracy than the crushing strength; it also represents both the compressive and tensile strength of the material, and is, therefore, a better test of the qualities of the brick. The transverse strength may be determined by the ordinary formula for transverse strength $R = \frac{3\,l\,W}{2\,b\,d^2}$ where R is the modulus of rupture, l the length between supports, b and d the breadth and depth of the brick, and W the load applied.

Prof. A. N. Talbot suggests (*Transactions* Am. Soc. C. E., Vol. XXVI, p. 415) the following method for applying this test:

"This test may be easily made, even if a testing machine is not at hand, as follows: Caliper the plunger of a hydraulic press, such as may be found in the machine-shop of any city, and attach a pressure gauge. Place the end of the plunger against a knife edge (easily cast) resting on the middle of the brick. Then the brick may rest on two knife edges placed for uniformity 6 ins. apart, and the stress of the plunger may be applied. After finding the pressure of the plunger, the modulus of rupture is easily calculated."

In testing for ratio of absorption, the brick should be placed in a drying or common oven and kept at a temperature of about 100° Cent. (212° Fahr.), for 10 hours or more if they have previously been saturated. They should then be weighed, and after the weight is carefully determined, placed in a vessel of water and kept for 24 hours at a temperature of about 15° Cent. (60° Fahr.), after which they should be taken out, the surface water carefully removed and again carefully weighed. The gain in weight, divided by the original weight, will give the ratio of absorption.

The presence of caustic lime is easily told by immersing the brick from one to four days in water. If caustic lime be present, it will make its appearance by breaking or cracking the brick or by "poppers" showing on the surface.

The specific gravity can be readily determined by weighing the brick, air dried W, after immersion W', and in water W'', and substituting in the formula—

$$\text{Specific gravity} = \frac{W}{W' - W''}.$$

The test for toughness or abrasive strength is usually made in an ordinary foundry tumbler. The brick should be tested a few at a

TABLE No. 5.

No.	Material—How Made.	How Burned.	Specific Gravity.	Absorption, percentage by weight of brick.	Transverse Strength.	Crushing strength cubes, plaster surface.	Crushing strength cubes, rubbed surface.	Observer.
1..	Drift Clay.....	Down draft.....	2.10	4.5	1 712	13 085	.....	I. O. Baker.
2..	" Stiff mud.....	Down draft.....	2.21	1.3	1 496	10 545	.....	" "
3..	" Soft mud.....	Up draft.....	1.87	4.8	1 429	6 190	.....	" "
4..	Fire Clay, Stiff mud, repressed....	Down draft.....	2.13	3.0	2 428	.....	13 402*	M. D. Buck.
5..	" Stiff mud.....	.....	2.18	2.9	2 197	.....	13 402*	" "
6..	" Stiff mud.....	.....	2.07	2.35	1 863	.....	11 688	" "
7..	Shale Clay, Stiff mud.....	Down draft.....	2.20	.01	2 645	.....	12 417	Gates and Page.
8..	" Stiff mud.....	" "	2.31	1.12	2 822	.....	13 402*	M. D. Buck.
9..	" †Stiff mud, repressed....	" "	2.21	1.20	1 680	5 260	12 010‡	I. O. Baker.
10..	" ‖.....	.....	2.29	.58	2 264	.....	13 402*	M. D. Buck.

* Tested to the limit of testing machine without crushing.
† This clay is from the Huron shale, Devonian period.
‡ This test was made by M. D. Buck.
‖ This clay is believed to be from the disintegration of the Salina shale.

time, with about 100 lbs. of "foundry shot," weighing not more than ¼ lb. to the piece. Heavy pieces of iron should not be used in this test, as they break the brick to pieces instead of wearing it. The different shapes of brick are apt to make a material difference in their wear during the first half hour. This is caused by some brick being manufactured with rounded edges, and some with square edges; the latter, being more easily broken or abraded, cause a greater loss in the material so made. For this reason they should be weighed after the first half hour, and the results of the second or third half hour used for comparison.

Table No. 5 is derived mostly from experiments of Prof. I. O. Baker and by M. D. Buck, C. E., and will give a general idea of the qualities of some paving brick in more or less successful use.

Table No. 6 is from the experiments by Prof. I. O. Baker, made under conditions closely resembling those recommended in this article. This table will give an example of the relative resistance to abrasion of brick during the first, second and third half hours in the rattler. It will be noted that brick No. 5, with rounded edges, lost only about the same percentage during each of the half-hour tests.

TABLE No. 6.

RESISTANCE OF BRICK TO ABRASION AND IMPACT.

No.	Material.	Quality.	Loss in per cent. of the original weight during—		
			1st half hour.	2d half hour.	3d half hour.
1.	Drift clay.....	Paver.....	2.0	0.8	0.8
2.	"	Under-burned.....	4.9	3.0	2.6
3.	"	Paver.....	2.1	1.3	0.7
4.	"	Under-burned.....	3.6	2.5	2.0
5.	*Shale clay.....	Paver.....	0.5	0.3	0.4
6.	"	"	3.1	1.5	1.3
7.	Fire clay.....	"	4.2	2.0	1.2

* Rounded edges.

Specifications.—Specifications should so define and limit the qualities of material to be used as to protect, on the one hand, parties for whom the work is done from the use of improper material, and the contractor, on the other, from capricious and arbitrary requirements.

The large majority of specifications for paving brick is entirely inadequate. They are vague and often meaningless, and in order, while

still in this condition, to protect the city from qualities of material, of which the municipal officers are (judging from the style of specifications) presumably ignorant, they are drawn so as to leave the selection and rejection at the discretion of such officers. The writer saw at one place 60 000 brick rejected and ordered off the street under such conditions by officers, who believed them to be defective. Brick of a poorer class of material, but having a more uniform and smoother form, were selected and used in their place. This fact was acknowledged by the same officers within a year after its occurrence, when the qualities of the two bricks had time to develop in the pavement. Certainly such a state of affairs is undesirable, and an attempt should be made to specify the qualities of the material, keeping, of course, well within the bounds of safety and possibility.

It should be remembered that each additional requirement cuts out certain classes of brick, lessens the competition, and in that way, and by reason of the extra cost in the manufacture of a higher grade article, increases the price of the finished pavement.

It must also be observed that with the present demand for paving brick and the state of the manufacture in many places where factories have been recently established, it will often be impossible to obtain brick which will fall within the higher limit herein named. Hence, the engineer should assure himself of the best quality of brick which can be obtained in sufficient quantities for his use, before adopting specifications calling for any particular grades of paving brick.

The following is suggested as an outline for specifications, to be modified more or less in accordance with the character of the work and the availability of material.

All paving brick must be homogeneous and compact in structure, free from loose lumps of uncrushed clay or from laminations caused by the process of manufacture, or fire cracks or checks of more than superficial character or extent. All brick so distorted in burning as to lay unevenly in the pavement shall be rejected. All brick shall be free from lime or magnesia in the form of pebbles and shall show no signs of cracking or spawling on remaining in water 96 hours. They shall be subjected to the following test for abrasion. Five brick shall be placed in a rattler which shall not exceed 28 ins. in diameter and which shall contain 100 lbs. of foundry shot of not more than $\frac{1}{4}$ lb. weight each, and said rattler shall revolve at a rate of not more than

25 revolutions per minute. They shall endure this test without sustaining a loss of more than from 1 to 2%* per half hour after the first half hour.

The brick shall have a specific gravity of not less than 2.00 to 2.20.* They shall not absorb more than from 1 to 5%* of water when dried at 100° Cent. (212° Fahr.) and immersed for 24 hours in water. They shall not crush under less than from 8 000 to 12 000 lbs.* per square inch when tested by preparing 1½-in. cubes with beds carefully rubbed to parallel and equal faces and tested between adjustable plates. They shall show a modulus of rupture of from 1 400 to 2 000 lbs.* per square inch when tested in full size on their side, the same to be computed by the formula $R = \frac{3\,l\,W}{2\,b\,d^2}$ in which R is the modulus of rupture, l the length between supports, b and d the breadth and depth, and W the load. All brick tested shall show an average equal to the limits named above, but a variation in individual specimens of not to exceed 10 to 20%* of the above limits will be allowed.

No brick not hitherto successfully used at other places will be accepted without a chemical analysis certified to by some competent chemist of reputation, which analysis shall show a chemical composition not differing materially from that of other paving brick in successful use.

All brick shall have a proper shrinkage and shall not differ materially in size from the accepted samples of the same make, unless said change is due to a change in die, such change to be acceptable to the city. Nor shall they differ greatly in color from the natural color of the well-burned brick of its class and manufacture. These qualifications shall be compared with the brick deposited at the time of letting or with others afterward substituted by the consent of both parties hereto.

The pavement shall be guaranteed for a term of two years from the date of its completion, and all brick injured by frost or shown to be defective in character or quality during this time shall be replaced by suitable material at the contractor's expense.

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* These figures include the limits from which the limit to be specified should be selected, in accordance with the qualities desired or possible under existing circumstances.

NOTE.—The writer believes Professor I. O. Baker first suggested approximately these limits for ratio of absorption and transverse strength. He also suggested that the limits be average limits from which a limit of variation be allowed which shall not exceed 20% on any sample tested.

The Pavement.—The use of brick for paving in the United States has been confined to the last two decades. Its first use was at Charlestown, W. Va., and at Bloomington, Ill., about 20 years ago. From these points, with their small beginnings, its use has spread until at present it is one of the most popular and widely used of all paving material.

A discussion of the principles that underlie brick paving would be a discussion of the principles of all paving. This material simply offers a surface covering, smooth and even, but not slippery, durable, economical and highly sanitary. It must be laid on a foundation drained and prepared as for all pavements. Beyond this, the success of the pavement depends on the proper selection of the material. With poor material it will prove a failure, as has been shown by the attempt to utilize common building brick at Nashville, Tenn., and elsewhere. With proper material it is an established success, and is destined, with the improvement in manufacture and the bettering and cheapening of the product thereby, to rank first in economy and availability of all paving material. In the majority of places it offers a possible local industry, when the availability of the local geological resources are better known and appreciated, and the different methods of utilizing them in manufacturing are more thoroughly understood.

In first cost the pavement depends on the nearness of the manufactories and the local resources suitable for foundations.

"For light traffic the fragmentary materials (rubble, gravel, sand, etc.), or sand with a layer of brick laid on their side, or 6 ins. of concrete, make good foundations, the selection depending on the local resources.

"For medium traffic, 9 ins. of stone or gravel, or 6 ins. of gravel or stone, with a layer of brick laid on their side, bedded in sand, or 6 ins. of concrete, will give good results.

"For heavy traffic the stone or gravel should be at least 1 foot in thickness, or the concrete at least 9 ins.

"All subfoundations which are retentive of water should be properly and thoroughly drained."*

In the average city the network of pipes and conduits laid below the street surface is the cause of frequent disturbances of the pavement which is often the leading factor in its destruction. The facility with which pavements can be taken up and replaced becomes, under such circumstances, quite important. In this, brick pavement is second to none. The brick, being uniform in size and shape, can be

* From a previous paper by the writer.

returned to their places by unskilled labor, an important point in smaller towns and cities. This is especially true if the fragmentary foundations are used, and if sand only is used in the joints. Where either coal tar or cement grout is used in the joints, the brick taken up are difficult and often impossible to clean, and new material has to be substituted. With sand in the joints the old material is readily cleaned, and the sand, in two weeks' time after laying, renders the pavement as impervious to the seepage of surface waters as the tar or cement.

The durability of brick pavements is a subject open to inquiry, for the limited time they have been in extensive use has been too short to answer this from practical experience.

The destruction of a pavement results from (1) the crushing by the wheel load; (2) the abrasion by friction of passing vehicles and the slipping of horses' shoes; (3) the impact due to the passage of loads over a rough surface, and the impact from the shoes of horses.

It has been found that the best paving brick will crush under loads varying from 8 000 to 18 000 lbs. per square inch, while granite will crush under loads varying from 13 000 to 22 000 lbs. per square inch. Brick, therefore, shows a strength sufficient to resist, with a large factor of safety, any load to which the pavement will be ordinarily subjected. The rattler test, the only test so far attempted for determining resistance to abrasion and impact, gives the comparative resistance of brick and granite (according to Prof. I. O. Baker), as follows:

Loss of granite in 1¼-hour rattler test, ½ to 3½ per cent.

Loss of paving brick in 1¼-hour rattler test, 2½ to 5 per cent.

The smoothness of brick will, in the opinion of the writer, more than overcome the difference in abrasive resistance of the granite. A loaded wheel as it passes over a rough pavement causes impact in proportion to the load and the degree of roughness of the pavement, and is the principal cause of wear in granite and cobblestone pavements, which is largely avoided with the smooth surface of brick.

The writer estimates the life of first-class brick pavements to be: for light traffic, 35 to 50 years; for medium traffic, 20 to 25 years; for heavy traffic, 10 to 15 years.

Prof. I. O. Baker, in his valuable pamphlet on "Brick Pavements," from which the writer has hitherto quoted, publishes a table based on his experiments, showing the probable length of life of brick in certain

streets of various American cities. From this table, Table No. 7 is reduced, somewhat changed in form from the original. The table is largely based on the tonnage observations of Captain F. V. Green.

The smoothness of brick renders it free from much of the objectionable noise of the rougher pavements.

Its freedom from decay, and its non-absorption of water, are sanitary qualities of considerable value. It produces little dust of its own and as it is not retentive of mud and dust, it can be readily cleaned.

Being smooth without being slippery, it offers comparatively little resistance to traction, while affording a fair foothold for horses.

Table No. 8 gives a concise statement of the manner of laying brick pavements in a number of cities of the United States, which will render the ordinary methods of utilizing this material quite readily understood.

TABLE No. 7.

SHOWING PROBABLE LIFE OF SEVERAL SAMPLES OF BRICK IF LAID IN CERTAIN STREETS OF PROMINENT CITIES OF THE UNITED STATES.

CITY.	STREET.	Width in feet.	DAILY TONNAGE.			Approximate life of brick pavements. Number of years required to wear off 50% from certain paving brick.				
			Total.	Per vehicle.	Per foot of width.	1	2	3	4	5
New York	Broadway, near Pine	40	10 905	1.39	273	9	11	19	7	4
New York	Fifth Avenue, opposite Worth Monument	40	3 740	.68	94	28	31	56	19	12
New York	Wall, corner Broad	27	2 357	1.00	87	30	34	60	20	13
Boston	Devonshire, opposite Post Office	27	5 301	.99	196	14	15	27	9	6
Boston	Washington	39	2 938	.80	75	35	38	70	24	15
Boston	Court Square	24	744	.67	32	83	91	165	53	35
New Orleans	Tchoupitoulas, near Poydras	40	6 204	1 81	155	17	18	34	12	7
New Orleans	St. Charles, near Washington	30	1 065	.94	35	76	83	151	51	32
Chicago	Wabash, near Lake	50	7 561	2.08	151	18	19	35	12	8
Chicago	Clark, near Madison	45	6 398	1.46	142	19	21	37	13	8
Chicago	La Salle, near Locust	36	2 756	.90	77	34	38	68	23	15
Chicago	Dearborn, opposite Washington Park	38	2 604	1.11	69	38	42	76	26	16
Philadelphia	Broad, in front of Pennsylvania Railroad Depot	65	9 237	1.52	142	19	21	37	13	8
Philadelphia	Chestnut, corner of Fourth	26	1 928	1.06	74	36	39	71	24	15
St. Louis	Locust, near Beaumont	36	3 691	1.13	103	26	28	51	17	11
St. Louis	Pine, near Garrison	36	2 554	1.16	70	38	42	76	26	16
Louisville	Main, near Third	61	4 176	1.25	69	39	42	76	26	16
Washington	Fifteenth, opposite Treasury	70	4 622	1.02	66	41	45	81	27	17
Washington	Sixth, between Pennsylvania and B	60	1 289	1.01	21	126	139	252	84	53
Buffalo	Main, near Swan	56	2 613	.83	47	57	62	113	38	24
Buffalo	Linwood, near Ferry	38	825	1.47	22	121	133	241	81	51
Omaha	Douglass, near Fifteenth	63	2 967	.62	47	57	62	113	38	24

Nos. 1 and 2 were made from drift clays.
Nos. 3 and 5 " " " shale clays.
No. 4 was made from semi-fire clay.

TABLE No. 8.

Details of Brick Paving as in Use in Many American Cities.

Locality.	Years in Use.	Foundation.	Depth of Sand Cushion.	Size of Paving Brick.	Filling of Joints.	Average Cost per Yard.	Brick—Where Made.
Atchison, Kans.	5½	4" of sand, course of brick flatwise.	1"	.....	Sand.....	$1 65	Atchison, Kan.
Alton, Ill.	2	6" broken stone, course of brick flat	1"	2¼ x 3¾ x 7⅞	"	2 16	Galesburg, Ill.
Bloomington, Ill.	18	Cinders 2" sand 2" course of brick flatwise.....	1"	" " "	"	1 40	Bloomington, Ill.
Burlington, Ia.	5	6" broken stone, cinders or sand, with course of brick flatwise.....	1"	2½ x 4½ x 8½	"	1 65	Burlington, Iowa.
Clinton, Ia.	4	6" broken stone with sand washed in.....	.....	2¼ x 3¾ x 7⅞	"	1 35	{Rock Island, Ill. {Galesburg, Ill. {London Mills, Ill.
Cedar Rapids, Ia.	.....	2½" sand with course of brick flatwise.....	1"	" " "	"		
Council Bluffs, Iowa	4	4" sand.....	.....	2¼ x 4 x 8	Sand	1 32	Council Bluffs, Iowa.
Columbus, O.	7	Broken stone or concrete.....	.....	2 x 4 x 8 to 3 x 4½ x 9	Tar or grout.....	1 50–2 25	{Columbus, O. {Zainesville, etc., O.
Cincinnati, O.	3	6" concrete	.....	3 x 4 x 9	Coal tar.....	2 50	Ohio factories.
Charlestown, W. Va.	22	3½" sand and tarred boards.....	1½"	2 x 4 x 8	Sand.....	1 15	Charlestown, W. Va.
Detroit, Mich.	3	.....	.....	2¼ x 4 x 8½	Coal tar	2 00	Ohio and Pennsylvania.
Davenport, Ia.	5	8" broken stone, sand washed in 6" broken stone, course of brick flatwise	.....	2¼ x 3¾ x 7⅞	Sand.....	{1 38 {1 70	Galesburg, Ill.
Dayton, O.	.....	6" concrete.....	2"	" " "	Tar or grout.....	.....	" "
Dubuque, Ia.	6 mo.	" "	.....	" " "	Sand.....	1 69	" "
Des Moines, Ia.	.....	4" sand, course of brick flatwise....	1"	" " "	"	.....	{Des Moines, Ia. {Galesburg, Ill. {Boone, Ia.
Evansville, Ind.	3	6" concrete.....	.....	2½ x 4½ x 8½	Sand	1 70	West Virginia, and Evansville, Ind.
Evanston, Ill.	2						
Fort Wayne, Ind.	1	6" broken stone.....	2"	2½ x 4 x 8½	Sand.	1 55	Bucyrus, O.
Findlay, O.	3	8" broken stone, 4" gravel or sand.	.....	2½ x 4½ x 8½	Coal tar.....	.....	West Virginia.
Fort Smith, Ark.	3	6" concrete	2"	2 x 3⅝ x 7⅝	Sand.....	.....	Fort Smith, Ark.
Galesburg, Ill.	6	6" sand, course brick flatwise.....	1"	" " "	"	1 40	Galesburg, Ill.
Hannibal, Mo.	2	4" broken stone, 3" sand, course of brick flatwise	1"	" " "	"	.....	" "

LAKE SUPERIOR
LAKE MICHIGAN
Minneapolis
Winona
Dubuque
Clinton
Rockford
Chicago
Council Bluff
Omaha
Lincoln
Nebraska City
Beatrice
St Joseph
Atchison
Leavenworth
Kansas City
Independence
Quincy
Hannibal
Jacksonville
Springfield
Peoria
Bloomington
Decatur
Litchfield
Alton
Mt Vernon
Terre Haute
Vincennes
Evansville
Cairo
Mt Carmel
Indianapolis
Memphis
Nashville
Louisville
Cincinnati
Columbus
Zanesville
Wheeling
Pittsburg
Cleveland
Erie
Buffalo
Rochester
Syracuse
Utica
Albany
Troy
Boston
Providence
Hartford
New Haven
New York
Philadelphia
Trenton
Baltimore
Washington
Richmond
Norfolk
Petersburg
Raleigh
Wilmington
Charleston
Savannah
Augusta
Macon
Columbus
Montgomery
Mobile
New Orleans
Natchez
Vicksburg
Jackson
Little Rock
Fort Smith
Fort Scott
Galena
Dixon
Ottawa
Joliet
Aurora
Elgin
Rockford
Freeport
Galesburg
Monmouth
Burlington
Keokuk
Fort Madison
Davenport
Rock Island
Muscatine
Iowa City
Dubuque
Winona
Prairie du Chien
Milwaukee
Racine
Kenosha
Waukegan
Detroit
Toledo
Sandusky
Cleveland
Akron
Canton
Steubenville
Wheeling
Parkersburg
Charleston
Huntington
Ashland
Lexington
Frankfort
Louisville
Bowling Green
Nashville
Clarksville
Hopkinsville
Paducah
Cairo
Memphis
Jackson
Vicksburg
Natchez
Baton Rouge
New Orleans
Mobile
Pensacola
Tallahassee
Apalachicola
Columbus
Montgomery
Selma
Tuscaloosa
Florence
Huntsville
Decatur
Corinth
Iuka
Tupelo
Holly Springs
Oxford
Grenada
Yazoo City
Meridian
Hattiesburg
Jackson
Brandon
Canton
Natchez
Port Gibson
Vicksburg
Greenville
Clarksdale
Helena
Little Rock
Pine Bluff
Arkadelphia
Hot Springs
Fort Smith
Van Buren
Fayetteville
Springfield
Ozark
Rolla
Potosi
Ironton
Farmington
Cape Girardeau
Sikeston
New Madrid
Caruthersville
Dyersburg
Jackson
Union City
Hickman
Columbus
Mayfield
Murray
Paris
Dresden
Martin
Trenton
Gallatin
Lebanon
Carthage
Springfield
Lebanon
Cookeville
Sparta
McMinnville
Shelbyville
Murfreesboro
Franklin
Columbia
Pulaski
Fayetteville
Huntsville
Athens
Cleveland
Chattanooga
Dalton
Rome
Gadsden
Anniston
Talladega
Selma
Montgomery
Eufaula
Dothan
Marianna
Quincy
Tallahassee
Monticello
Madison
Lake City
Gainesville
Ocala
Tampa
Bartow
Arcadia
Fort Myers
Punta Rassa
Key West
Cedar Keys
Fernandina
Jacksonville
St Augustine
Palatka
Orlando
Kissimmee
Titusville
Melbourne
Fort Pierce
West Palm Beach
Miami
Lake Okeechobee
Everglades
Big Cypress Swamp
Apalachicola River
Chattahoochee River
Flint River
Ocmulgee River
Altamaha River
Satilla River
St Mary's River
Suwannee River
Withlacoochee River
Ocklawaha River
St Johns River
Indian River
Kissimmee River
Caloosahatchee River
Peace River
Hillsborough River
Withlacoochee River
Escambia River
Yellow River
Choctawhatchee River
Apalachicola River
Chattahoochee River
Flint River
Ocmulgee River
Oconee River
Altamaha River
Satilla River
St Mary's River
Suwannee River
Withlacoochee River
Ocklawaha River
St Johns River
Indian River
Kissimmee River
Caloosahatchee River
Peace River
Hillsborough River
Escambia River
Yellow River
Choctawhatchee River

LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
Minneapolis
Dubuque
Rockford
Chicago
Milwaukee
Grand Rapids
Detroit
Toledo
Cleveland
Buffalo
Council Bluffs
Omaha
Davenport
Rock Island
Peoria
Springfield
Indianapolis
Columbus
Dayton
Cincinnati
Louisville
Nashville
Memphis
Vicksburg
Natchez
Mobile
Atlanta
Charleston
Savannah
Richmond
Pittsburgh
Erie
Albany
Boston
New York
Philadelphia
Baltimore
Washington
Kansas City
St. Joseph
St. Louis
Cairo
Evansville
Terre Haute
Fort Wayne
Lansing
Saginaw
Bay City
Grand Haven
Muskegon
Green Bay
Oshkosh
Fond du Lac
Racine
Kenosha
Waukegan
Joliet
Aurora
Elgin
Freeport
Galena
Dubuque
Burlington
Quincy
Hannibal
Jacksonville
Decatur
Bloomington
Lincoln
Springfield
Alton
Belleville
Centralia
Effingham
Mattoon
Champaign
Danville
Lafayette
Logansport
Peru
Kokomo
Muncie
Richmond
Hamilton
Middletown
Springfield
Xenia
Zanesville
Wheeling
Parkersburg
Huntington
Ashland
Portsmouth
Chillicothe
Athens
Marietta
Steubenville
Youngstown
Akron
Canton
Mansfield
Sandusky
Toledo
Findlay
Fostoria
Tiffin
Bucyrus
Marion
Delaware
Newark
Zanesville
Lancaster
Columbus
Springfield
Dayton
Hamilton
Cincinnati
Middletown
Richmond
Connersville
Shelbyville
Greensburg
Madison
Jeffersonville
New Albany
Corydon
Evansville
Princeton
Vincennes
Terre Haute
Lafayette
Crawfordsville
Frankfort
Kokomo
Peru
Logansport
Rochester
Plymouth
South Bend
Elkhart
Goshen
Michigan City
La Porte
Valparaiso
Hammond
Gary
Whiting
Indiana Harbor
East Chicago
Waukegan
North Chicago
Highland Park
Evanston
Chicago
Oak Park
Cicero
Berwyn
Aurora
Naperville
Wheaton
Elgin
Geneva
St. Charles
Batavia
Sycamore
DeKalb
Rockford
Belvidere
Freeport
Dixon
Sterling
Rock Falls
Morrison
Fulton
Clinton
DeWitt
Maquoketa
Anamosa
Cedar Rapids
Iowa City
Marion
Waterloo
Independence
Oelwein
Charles City
Mason City
Clear Lake
Forest City
Albert Lea
Austin
Rochester
Winona
La Crosse
Red Wing
Hastings
Faribault
Northfield
Owatonna
Mankato
New Ulm
Fairmont
Worthington
Windom
Jackson
Fulda
Luverne
Pipestone
Worthington
Spencer
Estherville
Emmetsburg
Algona
Fort Dodge
Webster City
Boone
Ames
Nevada
Marshalltown
Grinnell
Newton
Pella
Oskaloosa
Ottumwa
Centerville
Chariton
Creston
Shenandoah
Clarinda
Red Oak
Atlantic
Audubon
Harlan
Denison
Carroll
Manning
Glidden
Jefferson
Boone
Perry
Guthrie Center
Adair
Greenfield
Winterset
Indianola
Knoxville
Pella
Oskaloosa
Fairfield
Mount Pleasant
Burlington
Keokuk
Fort Madison
Hannibal
Quincy
Canton
Macomb
Monmouth
Galesburg
Kewanee
Princeton
Ottawa
Streator
Morris
Joliet
Kankakee
Watseka
Danville
Paris
Terre Haute
Vincennes
Washington
Jasper
Huntingburg
Tell City
Rockport
Boonville
Evansville
Henderson
Owensboro
Hawesville
Cloverport
Hardinsburg
Elizabethtown
Bardstown
Lebanon
Springfield
Harrodsburg
Danville
Stanford
Somerset
London
Corbin
Barbourville
Pineville
Middlesboro
Harlan
Hazard
Whitesburg
Jackson
Irvine
Richmond
Winchester
Mount Sterling
Maysville
Ashland
Catlettsburg
Huntington
Ironton
Portsmouth
Gallipolis
Point Pleasant
Ripley
Parkersburg
Marietta
Cambridge
Zanesville
Newark
Mansfield
Ashland
Wooster
Orrville
Massillon
Canton
Alliance
Salem
Youngstown
Warren
Ravenna
Kent
Akron
Medina
Elyria
Lorain
Sandusky
Fremont
Bowling Green
Findlay
Tiffin
Fostoria

Legend
Areas of Carboniferous deposits
Limit of drift
Cities where Paving Brick Factories are located
Cities having Brick Pavements
Cities having Factories and Pavements
L. ONTARIO
Rochester
Syracuse
Boston
Philadelphia
N.J.
Wilmington
Charleston
Augusta

TABLE No. 8—(*Continued*).

Locality.	Years in Use.	Foundation.	Depth of Sand Cushion.	Size of Paving Brick.	Filling of Joints.	Average Cost per Yard.	Brick—Where Made.
Hartford, Conn	6 mo.	Sand		3 x 4 x 9	Tar	2 75	Columbus, O.
Indianapolis, Ind	2	6" concrete		2¼ x 4¼ x 8¼	Tar and grout	2 40	Veterasburg and Brazil, Ind. Canton, O.; Ottawa, Ill.
Jacksonville, Ill	4	6" coal cinders, 1" sand, course brick flatwise	1"	2¼ x 4 x 8		1 30	Jacksonville, and Virden, Ill.
Kenosha, Wis	6 mo.	6" concrete or broken stone	1"	2¼ x 3¾ x 7¾	Sand		Galesburg, Ill.
Keokuk, Ia	6 mo	5" broken stone, 3" sand, course of brick flatwise	1"	2¼ x 4 x 8	"	1 68	Burlington, Ia.
Lafayette, Ind	3	8" gravel, 2" sand, course of brick flatwise	1"	" " "	"		Danville, Ill.
Louisville, Ky	1½	6" concrete		2½ x 4½ x 8½	Coal tar	1 65	Clovesport, Ky. New Cumberland, W. Va.
Mobile, Ala	5	Sand and course of brick flatwise	1"	2¼ x 4 x 8	Sand	1 50	
Massillon, O	3	6" sand	2"		Sand and tar		Massillon, O.
Memphis, Tenn	4	6 to 9" concrete		2½ x 4 x 8¾	Asphalt	2 78	West Virginia, and Robbins, Tenn.
Ottawa, Ill	2	6" sand, course of brick flatwise	1"	2½ x 4 x 8	Sand	1 37	Ottawa, Ill.
Omaha, Neb	5	6" concrete	2"	2¼ x 4 x 8	Sand	1 95	St. Joseph, Mo.; Atchison, Kan.
Peoria, Ill	6	6 to 8" gravel or 6" concrete	1"	4 x 5 x 12	"	1 75	Peoria, Ill.
Quincy, Ill	6	8" stone, 2" sand, course of brick flatwise	1"	2¼ x 3¾ x 7¾	"		Galesburg, Ill.
Rockford, Ill	1½	6" broken stone, 2" sand				1 34	Rock Island and Galesburg, Ill.
		4" broken stone, 2" sand, 1 course of brick flatwise	1"	2½ x 3¾ x 7¾	Sand	1 74	
Rock Island, Ill	4	6" broken stone, 2" sand, course of brick flatwise	1"	" " "	"	1 65	Rock Island, Galesburg, Ill.
		6" broken stone, 2" sand	1"	" " "	"	1 40	Rock Island Ill.
Wilmington, Del	2½	Broken stone and sand		2½ x 4¼ x 8¼	Sand, tar or grout	2 00	West Virginia and Rhode Island.
Scranton, Pa	5	Gravel and sand, or 4" concrete		2¼ x 4 x 8	Tar and sand	2 10	New Cumberland, W. Va. Springfield, Ill.
Springfield, Ill	6	6" cinders		2 x 4 x 8	Sand	1 50	Virden, Peoria, Ill.
Terre Haute	1	8" rubble	2"	2½ x 4¼ x 8½	Grout	2 25	Canton, O.; Brazil, Ind.
Wheeling, W. Va	10	8" gravel	2"	2 x 4 x 8¼	Coal tar	1 35	New Cumberland, W. Va.

Note.—The above table was derived partially from data furnished by E. R. Ruttan, City Engineer of Winnipeg, Manitoba.

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CARBON AND ITS USES IN ELECTRICAL ENGINEERING.

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Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In the year 1810, Sir Humphry Davy connected the poles of a battery of 2 000 elements by two charcoal points, and produced one of the most brilliant artificial lights that had doubtless ever been seen.

So little value was attached to this experiment that it was merely entered in the note book of the great physicist, and remained there apparently unnoticed until 12 years later, when it appeared as a communication to the Royal Society. Scarcely do we find a more striking example of the great advancement in electrical science than when we note that this bright spark has grown in strength and beauty, until now there are required to feed its ever-spreading rays 200 000 000 of carbon pencils for the present year in the United States alone.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

In electrical engineering, the term carbon is used to designate an artificial solid, which, through mechanical or chemical means, is derived from some of the natural forms of carbon. It is moulded under great pressure into cylindrical pencils for arc lighting, or into rectangular blocks or plates for battery or other uses. It is not the purpose of this paper to describe minutely the process of making carbon, nor is it necessary, as there are published descriptions which cover the ground fairly well. However, an outline of the general principles may not be out of place.

The materials usually employed are coke and pitch. The coke should be as free from solid impurities as is obtainable. Petroleum coke is largely used, although other varieties are often sufficiently pure for the purpose. It is ground to powder, and the volatile components are driven off by heating in retorts. Melted coal tar pitch is then thoroughly mixed with it, and for some kinds of carbon lampblack is also added. The mixture is then cooled, again ground to powder, and is then ready to be moulded or forced.

The process of moulding consists of filling the material into steel moulds, which are made in two equal parts, so arranged that the lower half of the mould will contain a sufficient quantity of the material for the entire charge. The upper half is then placed in position upon its counterpart, the mould is placed in a furnace and heated sufficiently to soften the fusible ingredients. It is then put under a pressure of about 400 tons, after which the 16 pencils, or carbons as they are called, are removed from the mould. After cooling they are ready for the next process, which consists in handling the carbons one by one, examining and trimming off the webs which usually occur between the individual pencils as they lie in the mould; they are then packed in furnaces holding from 30 000 to 50 000, where they are baked at a high temperature for about 100 hours. After cooling for a like period they are sorted for straightness. A portion are then sent to the consumer, but a large portion are first coated with copper.

The process of forcing is proximately the same as that of moulding until the material is ready for the moulds; then, instead of being moulded, it is heated and made into cylindrical plugs, which are placed in a heavy iron cylinder, and, by means of a plunger driven by hydraulic pressure, the plastic material is forced through a steel-bushed orifice and comes out in the shape of a continuous cylinder,

which is cut to the lengths desired. The carbons are then sent to the furnaces, and from this point the process is the same as for the moulded.

The forcing process permits of a wide range of shapes, as by changing the size of the steel-bushed orifice, cylindrical carbons can be forced having a diameter of $\frac{1}{16}$ in., and from this size up to or even above 4 ins. in diameter. Many other shapes besides cylindrical can also be made, such as plates that are not much over 4 ins. wide and of a thickness of from $\frac{1}{8}$ to $1\frac{1}{2}$ ins. or over. These are cut into short lengths and used for dynamo or motor brushes. Plates as small as $\frac{1}{4} \times \frac{1}{8}$ in. are also forced for small generator or motor brushes.

There is a great difference in density and structure between moulded and forced carbon. The pressure under which moulded carbon is made is about 8 300 lbs. per square inch, while by the forcing process the pressure required is double or three times as great. By the method of forcing, the material is crowded together as it is pressed toward the small end of a conical chamber and is finally forced out at the vertex, thus giving a combination of lateral and end pressure.

By the method of moulding, the carbons receive side pressure only. Under the side pressure, the material tends to laminate in planes parallel to the axis of the carbon; while under end pressure, the planes of lamination are at right angles to the axis. As usually made, the pressure is not sufficient to produce distinct lamination; but it is evident that the structure of the material is inclined toward this class of formation, as in the case of slate rock which is laminated in planes at right angles to the lines of pressure. Under certain conditions, lamination may be observed both in moulded and forced carbon.

Carbons as they are usually made for arc lamps are about $\frac{7}{16}$, $\frac{1}{2}$ or $\frac{5}{8}$ in. in diameter, by about 12 ins. in length. In some cases pairs are used, a carbon 7 ins. and one 12 ins. usually constituting a pair. Besides those there are several other sizes in use; for searchlights and for many of the large lighthouses, carbons as large as $1\frac{1}{2}$ ins. in diameter, and often larger, are employed.

In addition to the ordinary pencils, many other forms may be moulded, such as cups or crucibles, or almost any design where the material can be retained in moulds and submitted to great pressure. Plates are made 12 to 14 ins. square, and in thickness from $\frac{1}{32}$ in. to over 1 in.; and even larger sizes are often made.

In its physical properties carbon varies greatly, the variation depending upon its composition and treatment in the process of manufacture. The hardness may be from that of chalk to that of crockery, and its specific gravity may vary to about the same extent. It is quite brittle, and this property is retained through all its stages of hardness. The tensile strength and resistance to crushing increase with the hardness.

For cutting carbon the emery wheel is generally employed; it can be drilled or cut in the lathe with steel tools, but its effect is to wear them away very rapidly; even diamonds can be used as cutting tools but a short time. On the hardest specimens these operations are performed with difficulty even with the best of tools.

As applied to electrical engineering, the most important and interesting use of carbon is in the arc lamp; here we find phenomena that are wonderful even in the light of the most advanced science. If two ½-in. carbon pencils be placed with their points in contact, and are included in an electric circuit having a current of 10 ampères, a slight amount of heat will be developed in the body of the pencils, which will be greatest at the point of contact; if, while the current is still passing, the pencils be separated a few millimeters, an arc of great luminosity and heat will be formed. If the poles of a voltmeter be connected with the pencils, the voltage due to the resistance of the arc will be seen to vary directly as its length, or nearly so; at about 20 volts the arc will be scarcely visible, and will increase in brilliancy and heat as the points are separated until the voltage reaches about 50, when the light will appear to be the most brilliant. At a point somewhere above this voltage, possibly 70 or higher, the arc will go out with a snap.

In the above case, if the current be maintained constant, of course the watts required will vary as the voltage, and this variation of the total watts is employed by all makers of arc lamps as a means of moving the feeding mechanism. This, in some lamps, may be so delicately adjusted as to move the carbons toward each other when the distance between the points has increased an amount corresponding to 1 volt, while many lamps require an increment of 5 volts to cause the feeding device to respond.

One of the most notable points in regard to the burning of the carbon arc, is that the temperature in the positive carbon rises much

higher than in the negative. It is noticed that when we extinguish the arc by turning off the current, the point of the positive carbon remains incandescent after the negative point has become black; the intensely heated crater formed on the positive carbon radiates far more light than the incandescent point which is formed at the end of the negative. The consumption of the positive is about twice as great as that of the negative when burned in the air; if burned in a vacuum, then the positive only is consumed. These facts seem to indicate that the larger part of the energy of the current is expended upon the positive carbon. A large part of the energy expended upon the arc is doubtless used in maintaining a counter electro-motive force, and another portion is absorbed in the conversion of solid carbon into vapor.

The arc may be colored by the introduction into the carbon of almost any foreign substance, and the color is characteristic of the substance employed, as in the case of the Bunsen flame; and as there are but few substances which are not volatile in the electric arc, the range of color is very large. The intensity of temperature is, without question, highest in the center or inner portion of the flame and lowest toward the outer circumference; for this reason the vapors of substances arrange themselves in concentric envelopes—those which volatilize at the highest temperature taking positions nearest the center, those which volatilize at the lowest temperature becoming the outer envelope.

The carbon flame affords one of the best subjects for spectrum analysis; it is therefore of great value for this purpose, and by its use the field of the spectroscope has been greatly enlarged.

It is perhaps important to note that, aside from the color effect of foreign substances in the carbon pencil, there is in most cases a reduction of the light and generally a lengthening of the arc; this may be accounted for on the supposition that foreign substances usually volatilize at temperatures lower than carbon and hence supply vapors which radiate less light, and, volatilizing more rapidly, the quantity of the vapor is increased and a corresponding reduction of voltage may also be noted. If the foreign substances are not homogeneously incorporated with the carbon, the arc will be unsteady and the light will be unsatisfactory.

In the burning of arc-lamp carbons, there is always a quantity of carbon dust that falls from the burning points; this is not a product

of combustion, but particles of carbon, which are detached and thrown off from the highly heated points by calcination. Many attempts have been made by inventors to reduce or prevent the loss of life of carbons due to this cause. Some degree of success has been attained by introducing into the carbon ingredients which, fusing at a comparatively high temperature, become slag and mix with the detached particles and prevent them from falling off; and retaining them until they are consumed, the life of the carbon is prolonged to a very marked degree.

The hissing sound so frequently observed in the arc-light carbons is a matter of importance. There seems to be a strong current of air and vapor moving between the highly heated points; when this current impinges in a certain manner against the point toward which it flows, hissing will be the result. To illustrate: if a jet of air be blown from a small tube, at high velocity, against a solid substance, a hissing sound will or will not be produced, depending upon the velocity of the air, the nearness of the solid and its configuration.

Many experimenters have endeavored to obtain a quiet, steady arc by the introduction into the carbon of foreign matter, which, by producing vapor more easily than carbon, will so modify the conditions as to prevent hissing; and, with a view of holding the arc in the center, a core is used. This core is simply a center, which may be $\frac{1}{16}$ in. or more in diameter, of a material that is different from the body of the pencil and contains more or less of the foreign matter.

Some of the most quiet and steady-burning carbons that are in use have been obtained by the use of foreign matter and a core. Carbons are also made with hollow centers, through which solutions of salts are simply poured, a sufficient quantity being left therein to produce the desired result.

As early as 1867 M. Carré coated carbons with metals, such as zinc and tin; and about the same time Mr. Joseph Van Malderon experimented with carbons electroplated with copper. Carbons have, therefore, been electroplated almost from their first introduction, and copper has been the metal used. The only reason the writer has seen assigned for this use of copper is that it reduces the resistance, conveying the current to the end of the pencil with but little loss of energy. The life of the carbon is increased by coating with copper from 8 to 10 per cent.

The total resistance of an uncoated pair of ½-in. carbons, in a newly trimmed lamp, is about .20 ohm, while the total resistance of the lighted lamp is about 5 ohms. It is evident, therefore, that the resistance of the carbons is about 4% of the total resistance of the lighted lamp. The resistance of the lamp coils may be 2 per cent. The decrease of resistance due to copper coating will not account for the increase of the life; this is due, in the writer's opinion, to the fact that the copper tends to support and retain the particles of carbon that are detached from the points by calcination; to some extent, also, the fused copper forms in liquid beads, and, by absorbing the calcined carbon dust, tends to prevent its loss.

A comparatively new use for carbon is found in the carbon brush for dynamos and motors; here carbon is substituted for the copper brush, and hence retains the name, which appears like a misnomer. Carbon brushes reduce the cutting of the commutator and the sparking to almost nothing. The same commutator may be used for years with carbon brushes which, if copper were used, would be worn out in a few months. The quality of the carbon brush is of great importance; it must be of fine texture, sufficiently hard, and should act in some degree as a dry lubricant, and it should not give a squeaking noise. These are points that can be provided for by the manufacturer. Much difficulty is sometimes experienced by heating. This, of course, is a question of conductivity, and can usually be remedied by making the brush larger, or by coating it with copper, or by doing both.

The telephone is indebted for a large measure of its great success to artificial carbon. Here its value depends upon the principle that an increase of pressure produces a decrease of resistance. The writer is inclined to think, with Mr. S. P. Thompson and others, that the increase of pressure simply makes a more perfect contact. As the resistance of carbon is higher than that of metals, it is, in some cases, an excellent material for this purpose, and especially where moderate resistance is required.

Among the advantages of carbon for electrical resistances, we may note the fact that it can be heated almost to a red heat and held at this temperature, without undergoing any change whatever; and, being practicably infusible, it will stand for a short time very high temperatures, even in the atmosphere, without suffering any deterioration. If held long at a red heat, however, in the air, it will calcine and

sometimes oxidize. Carbon has also the remarkable property of showing a reduction of resistance as the temperature rises. At high temperatures this is very marked; for example: the decrease in resistance of an incandescent lamp filament at a white heat may be one-third of its resistance when cold. At temperatures below a red heat, however, the change of resistance is of comparatively little importance.

Some of the difficulties that attend its use as a resistance material are as follows: the resistance of carbon varies between wide limits; two carbon pencils ½ in. in diameter and 9 ins. in length could be selected, of which one would have a resistance of .20 ohm and the other .07 ohm. The forced carbon being more dense is always lower in resistance than the moulded, other conditions being the same. The resistance, however, may be largely controlled by variations in the manufacture.

The connection between carbon and a metal conductor often becomes a troublesome point, especially if high temperatures are to be used. For low temperatures the carbon may be electroplated with copper and the metal conductor may then be soldered; but for high temperatures the connection must be made by some form of clamping device.

Carbon is not used as a resistance where calibrated resistances are required, owing to the difficulty of predetermining its exact resistance. For resistance purposes, carbon is used in the form of pencils as small as ⅛ in. in diameter; larger sizes are also used; it has also been used in the granular form and as a powder.

As a contact piece, where contacts must be made and broken frequently, carbon has a great advantage in many places over metals; and frequently, where metals are used in switches for contacts for large currents, carbon blocks are successfully used as a last point of contact. In such places as these last mentioned, carbon often gives a long arc, but even where one pole is metal, instead of burning the metal the current seems to expend its energy on the carbon, which suffers but little and is renewable.

Carbon is almost universally used in primary open-circuit batteries for the positive pole, and for this purpose it is made in the form of cylinders or plates. It is not acted upon at ordinary temperatures by any acid or other liquid known to chemistry, and in batteries it is easily depolarized. Carbon is also used, to a limited extent, for crucibles;

and, when mixed with clay, stands very high heats without oxidization.

It is remarkable that while carbon is made in a variety of forms, its uses are almost entirely confined to electrical engineering; and as we note the rapid advancement of this new department of scientific work, we may also note, as one of the changes it has brought to our century, this new industry—the manufacture of carbon.

A slight idea of its growing magnitude in the United States may be gained from the fact that it claims an investment of over $1 500 000.

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THE GUADALAJARA ELECTRIC-LIGHT INSTALLATION, UTILIZING THE FAMOUS JUANACATLÁN WATER-FALLS, 28 KM. DISTANT FROM GUADALAJARA.

By RAFAEL M. DE AROZARENA, Mechanical Engineer, Member of the American Society of Mechanical Engineers, and of the Association of Engineers and Architects of Mexico.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Among the industrial enterprises taken up in Mexico by local capital, the plant for the supply of the electric light and power in the City of Guadalajara, Jalisco, is one of the most notable, not merely because of its magnitude with respect to the investment required, but also because the project necessitated the use of novel and special machinery, the source of supply being located 17 miles from the base of demand.

The problem was to install at the falls of Juanacatlán (the Niagara of Mexico) a hydraulic and electric plant which should be capable of

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

supplying in the city of Guadalajara—distant 17 miles—sufficient electric energy to operate some 950 H. P. in the form of light, divided up as follows: Seven thousand five hundred incandescent lights of 16 candle-power each, and 200 arc lights of 2 000 candle-power each.

After careful consideration and study, the plans were projected and machinery ordered from the following well-known houses: The electric machinery and material from the Thomson-Houston International Electric Company, of Boston, Mass.; the turbines and piping from James Leffel & Company, of Springfield, O.; the valves from the Ludlow Valve Manufacturing Company; the countershaft, clutches, pullies and bearings from the Hill Clutch Company, of Cleveland, O.; and the iron poles for carrying the wire on the main line from the falls to the city—a distance of 17 miles—as well as for the wires in the city, from the Reading Iron Company, of Reading, Pa.

The falls of Juanacatlán are on the Grande River, and situated some 17 miles (28 km.) southeast from the city of Guadalajara. The whole volume of the river falls at this point some 58 ft. in a perpendicular line, with the shores above the falls sloping gently to the stream. Below the falls, the shores on both sides slope almost at an angle of 45°, leaving but little room at the bottom upon which a building could be erected, for which reason the building was projected of three stories, as shown by the section of Plate No. 1.

The work above the falls was simple and of easy execution, for, the river being very wide at this point, its depth is small, and a masonry wall some 3 ft. high was built, running across the river for two-thirds of its width and at an angle of 45° to the line of the falls, the object of which was to carry the greater part of the water in the river to a given point on its left bank directly at the falls; then a raceway was formed 14 ft. high by 14 ft. wide, from which the 7-ft. diameter conduit pipe carried the water down to the turbines. This conduit pipe is made of wrought-iron sheets ¼ in. diameter, riveted together, no flanges being used. At the head of the pipe is located a vent pipe, to protect the pipe from collapsing when the wooden gate which is located at its entrance is closed. The pipe, to conform to the nature of the fall at this point, has two elbows of 90° and one of 45°, from which on a horizontal line it connects the three turbines together, reducing its diameter from 7 to 6 ft. between the first and second turbine, and from 6 to 5 ft. between the second and third tur-

bine. Directly in line with the piping are located the three horizontal double Leffel turbines, and between the turbines and the conduit pipe in the connecting pipes, which are 4 ft. 6 in. diameter each, are located Ludlow straightway gate valves, which are opened and shut by geared hand wheels, thereby permitting the water to be closed off from each or any of the turbines without having to stop the others.

The turbines located on the first floor of the building are horizontal double wheels, placed in one case; both wheels are connected directly on to the same shaft, which extends out from the case on both sides, and has at each end a sheave pulley for transmitting the power. Each turbine is 20 ins. diameter, and has its independent draft tube; and as the river is known to rise in the rainy season from 1 to 2 m., the turbines were placed 16 ft. above the bed of the river, with draft tubes, all 10 ft. long, discharging into a well 4 ft. deep (which is the average depth of the river in the dry season), making the distance from the center of the turbines to the surface of constant water in the tailrace exactly 12 ft. This mode of setting turbines with draft tubes has given the writer excellent results here in Mexico.

The power of each set of turbines is 550 H. P., making a total of 1 650 H. P. The power is transmitted from the turbines to a countershaft placed in the second floor of the building. A rope driver is used, of endless manilla, plumbago, tallow-laid rope, 1 in. diameter, using an idler pulley on a stress car, with weight. Each pulley has 15 grooves to receive the 15 strands of rope.

The 42-in. diameter pulleys on the turbines connect with clutch pulleys on the countershaft of 84 ins. diameter, giving a speed of 6 594 ft. per minute to the rope. This driver, when the speed does not exceed 7 500 ft. per minute, by using sheaves at least 40 times the diameter of the rope, the writer has found to be very satisfactory, and on account of its duration much cheaper than belt drivers, especially for damp places.

In Orizaba, over two years ago, the writer used this driver for transmitting 188 H. P., for electric-light work; the rope, which to-day shows no signs of wear, is the same one which has been used from the start, and the plant has run on an average 11 hours every night, without any interruption. Great care must be taken, however, not to put too much weight on the stress car which carries the idler pulley.

Arc-Lighting Dynamos.—For furnishing current to operate the arc

lights, the familiar Thomson-Houston "M. D." dynamos were employed. They have capacity each for 50 arc lights of 2 000 candle-power, or, in other words, a rated output of 25 kilowatts. The current strength is 10 ampères and consequently the maximum voltage 2 500.

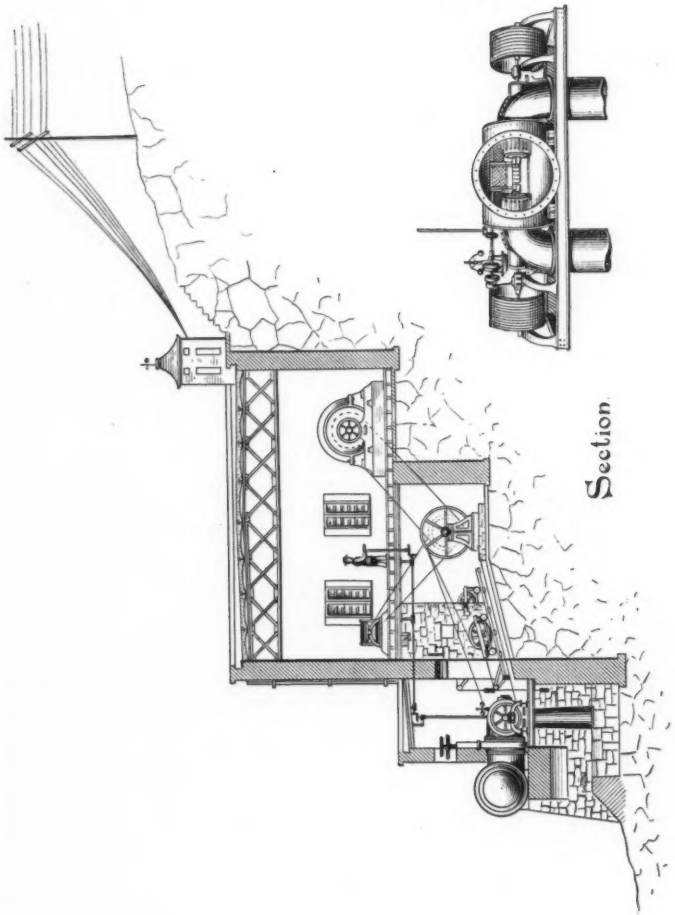
The dynamos weigh 3 tons each, require floor space of about 15 sq. ft., a belt speed of 3 863 ft. per minute, with a consumption of nearly 50 H. P. under full load. Four such dynamos are in use, operated two in "series" to avoid multiplicity of wire. Thus, for a total capacity of 200 lights, only two circuits leave the generating station. Each dynamo is supplied with the usual ingenious and efficient "automatic regulator and controller," without which it would be well-nigh impossible to fulfill the condition. With such, however, lamps may be lighted or extinguished without the necessity of paying attention to the dynamo.

Arc Circuits.—The current is conveyed from the dynamos by means of highly insulated copper wires to a slate switch board arranged for any desired combination of machines; from here through current indicators to the lightning arrestors, from which the wires are led to the pole line. The pressure utilized being rather above the safe limit, the insulation of the circuit is augmented by fastening the wires upon oil insulators, mounted upon wooden cross arms. The construction of these insulators is such that leakage is practically prevented, as, in order to escape by leakage, it would be necessary for the electricity not only to overcome the wire insulation, but also to pass through two strata of oil, the insulating qualities of which are well known.

In the city of Guadalajara these circuits are led to a central distributing station, in which is placed a duplicate plant of lightning arrestors, switch boards and testing instruments. It is from this station that the lights are directly controlled.

Arc Lamps.—Standard double carbon arc lamps are used throughout the city. They are suspended from steel cables stretched from corner to corner, supported by house structures arranged with pulleys and cables so that the renewal of carbons may be readily attended to.

Incandescent Dynamos.—As but one dynamo was desired for this installation, one of special construction was supplied. It is of the alternating current type, has 40 pole pieces, and yields approximately 350 ampères at 1 000 volts, or, say, 350 kilowatts.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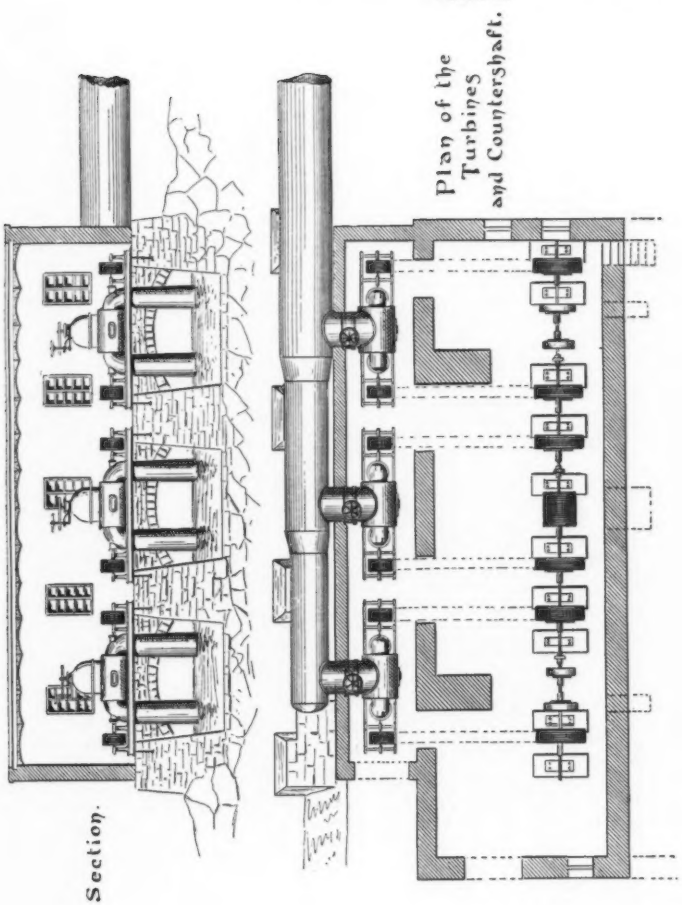
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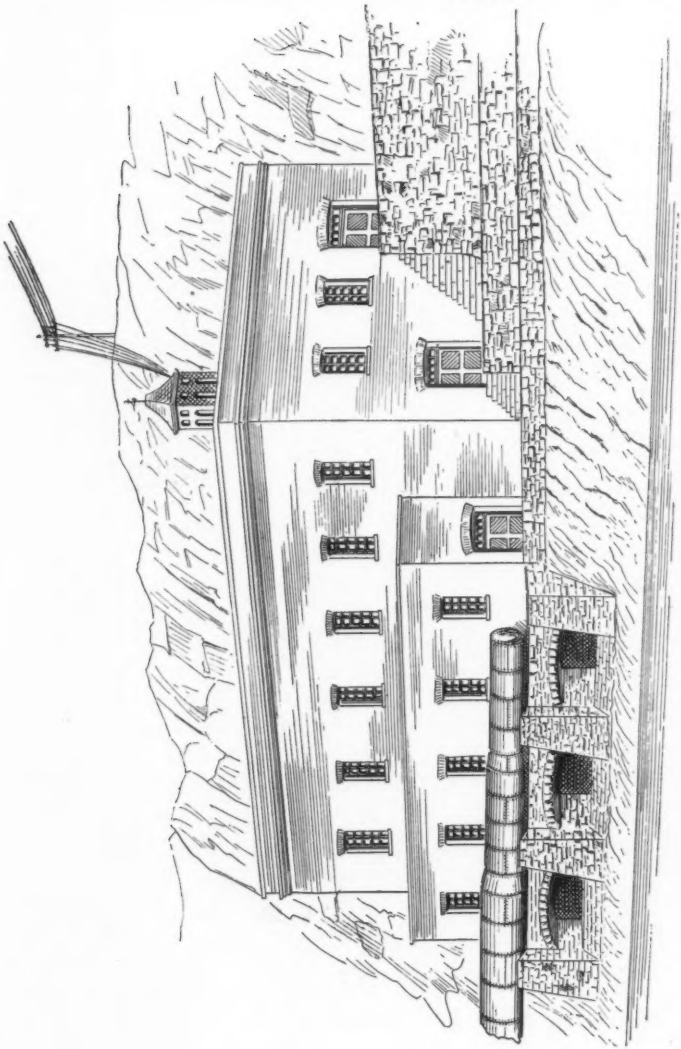

The dynamo weighs between 30 and 40 tons, requires a floor space of 216 sq. ft. and a belt speed of 5 024 ft. per minute, consuming, under full load, some 750 H. P. The armature is run at the low speed of but 300 revolutions per minute, and the shaft, which is 9 ins. in diameter, is furnished with a 60-in. diameter pulley, having 28 grooves for 1¼-in. rope, as this dynamo is driven from the countershaft with a rope driver the same as between the turbines and the countershaft. The 40 pole pieces forming the field magnets are excited by means of a separate exciter, known as "D–5," and having an output of 5 kilowatts at 125 volts.

Various indicating instruments are installed, enabling the operator to tell at a glance what load is upon either machine and at what pressure the dynamos are operating. To convey with moderate loss so great a current as 350 ampères over a distance of 17 miles would require a copper wire having a sectional area of about 4 sq. ins. Such a conductor could not be used, for practical reasons, to say nothing of the expense, which would be itself prohibitive. As the proper section of copper wire varies directly with the current it is necessary to carry, it is obvious that, in order to transmit such power over a wire of moderate size, the quantity of current must be reduced. Without changing the quantity of wire this may be done by increasing the voltage, which, accordingly, was raised to a maximum of 5 000, thus reducing the current to about 70 ampères, and the size of the wire to one having a sectional area of .1662 in.

Step-Up Transformers.—To so increase the voltage from 1 000 to 5 000, a bank of 10 step-up transformers was installed. These are built upon the lines of the type "F" oil transformer manufactured by the General Electric Company. They transform the energy of the dynamo at an efficiency of about 98%, delivering to the line, therefore, 98% of the energy supplied them and at five times the pressure. The transformers are so designed as to be filled with oil, the insulating qualities of which are very high, thereby increasing the insulation resistance of the transformer, rendering it less subject to damage from lightning discharges, and, indeed, restoring the insulation, should it be destroyed by means of a stroke of lightning. The transformers are banked or operated in multiple. They have a capacity of 30 kilowatts each; weigh approximately 1 300 lbs., each requiring 12 cu. ft. of space. They are protected by a simple but effective system of circuit

breakers and fuse connections, and the current passing from them is carried through a special lightning arrestor designed to protect circuits of extraordinary high potential.

Main Circuit.—The cross arms, pins and insulators used in connection with the alternating circuit are precisely the same as those described under the heading "Arc Circuits."

Step-Down Transformers.—The high potential incandescent line carried to the central station in the city of Guadalajara is passed through lightning arrestors and safety devices, as described above, to the bank of step-down transformers, which reduces the pressure to 1 000 volts, at which potential it is carried through the streets of Guadalajara as in ordinary installations. In the Guadalajara Central Station switch boards are installed, enabling any combination of lights and circuits to be made, without attention to the dynamos at the point of generation. The number of lights in operation, the physical conditions of the circuits, and indeed the conditions of the dynamos at the generating station, can all be determined in Guadalajara. Telephonic communication is established between the two stations, enabling those in charge to give their directions promptly.

As a further protection against lightning, which in the State of Jalisco is very severe, iron poles have been used, each surmounted by a pointed lightning arrestor rising some 3 ft. above the top of the pole, or, say, 5 ft. from the highest current conveying wire. These arrestors are, of course, mechanically connected to the iron poles, besides which they are joined to each other by means of an iron wire. This is considered the most effective protection possible, as it produces an artificial earth above the wires conveying the electrical current.

NOTE.—The president of the company, Mr. José María Bermejillo, is an old resident in the country and very well known throughout Mexico on account of his enterprising character. This gentleman owns the Juanacatlán Falls, and has long been endeavoring to work up this company.

The writer wishes to express his sincere gratitude to Mr. Samuel C. Peck, of the Thomson-Houston International Electric Company, and to Messrs. James Leffel & Company, for having so willingly assisted him in compiling all the necessary information towards the construction of this important work.

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THE RELATIVE MERITS OF WORKING HOISTING MACHINERY BY STEAM, WATER AND ELECTRICITY.

By GEORGE A. GOODWIN, Senior Vice-Pres. of the Society of Engineers; Assoc. M. Inst. Civil Engineers; Whitworth Scholar.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In approaching this subject, one should do so with an unbiased mind; unfortunately many people who have a predilection for one system, or who, perhaps, may be the parent of a particular method of utilizing power, are too prone to conclude that that system is best suited for each and every purpose. The author cannot urge too strongly the fact that each installation should be specially and individually considered. The advantages and disadvantages that would accrue from the application of each should be considered, with the result of selecting the one which shows least objections, for no doubt none would be perfect.

Since the early days when the ordinary wheel and axle windlasses

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

were used for all kinds of lifting and hoisting, vast strides have been made, first, in the application of steam, then of hydraulic power, and lastly of electricity. All of these powers can, without doubt, be employed for working all the known hoisting and lifting machines, such as traveling and fixed cranes, travelers, Goliaths, winding engines, hoists and lifts, but not all with equally useful and economical effects. The questions that arise, and which concern all engineers who have to select and decide on a system of power for application to a certain purpose, are:

First.—Which system is most economical to work?

Second.—Which system entails the least initial outlay?

Third.—Which system has the fewest disadvantages?

The author would here remark that he does not profess to be able to say anything novel about hoisting machinery *per se* that is not already familiar. He will confine his remarks to comments on the suitability of each system to the various purposes to which they can be applied, their advantages and disadvantages, investigating the *pros* and *cons* of each, and, by giving some figures on the costs of installation and working, he hopes, by inviting friendly criticism combined with the statements of the valuable experience gained by other engineers on this side of the Atlantic, to put on record reliable data which he trusts may be of value to the members of the profession.

Before entering into the details indicated, the following postulates should be conceded.

First.—That steam-worked machines are supplied with steam drawn from a center or distributing boiler or boilers, or that each machine is supplied from a self-contained boiler.

Second.—That where hydraulic power is used, the water is supplied from a central pumping station and distributing plant.

Third.—That where electricity is used, the current is supplied, as in the hydraulic system, from a generating plant from a central station; for, obviously, if the hydraulic or electric power were generated by an engine self contained on the machine, the conversion of the energy in the steam into hydraulic or electric energy, to be after re-converted into mechanical power, would entail considerable loss in useful effect as compared with driving direct, unless some system of storage were introduced.

Steam.—To obtain the full advantage of steam, when used as the

motive power, it is necessary, primarily, that all the machines so driven should be supplied from one or more batteries of boilers and should be regularly at work, in order that the average demand for steam should bear a high proportion to the maximum drawn off and for which the boilers are designed, so that the firing and evaporation may be as nearly as possible constant. If this condition of working does not exist, a considerable loss of efficiency must result.

By reason of the difficulty of regulating the supply and the combustion of the fuel, which naturally cannot be quickly adjusted to accord with the varying requirements, particularly if mechanical stokers are used (which are so necessary to economical firing), it follows that at times of small demand for power there will be a relative excess of steam formed going to waste through the safety valve, while during large and sudden demands there will be a deficiency; and in case of the former, all the working expenses, as well as coal and water, go on uninterruptedly, thus reducing the efficiency and raising the cost of working abnormally high.

Again, there must always be a slight continual loss by radiation along the steam pipes and boilers however well protected by some of the many non-conducting compositions, and which increases proportionally when the demand for steam is low.

One method of lessening the cost of working is by keeping the boiler output constant. The overcoming of the difficulties of storing heat energy as it is formed in excess of the supply drawn has recently been brought forward by Mr. D. Halpin, of London, and referred to by Professor G. Forbes in his paper read before the St. Louis National Electric Light Association on March 1st, 1893.

It is well known that when a large plant is at work, the individual units being spread over an extended area, the demand for power must fluctuate, and that the minimum and maximum loads differ very greatly from each other, the maximum load sometimes reaching from three to four times the average load. To cope with this fluctuation, it is necessary to supply motive power capable of handling the maximum demand when it arises, and which is consequently three to four times the capacity that it need be if the power were required at an even rate and of the same total amount.

The system may be briefly described as follows:

A sufficient number of ordinary boilers are fitted up and worked

night and day, and are of such a capacity that the steam generated by them during that period will suffice for a day's work; to these are attached what are styled "Thermal Storage Reservoirs," which are proposed to be of a vertical cylindrical form, and the live steam taken from them direct to the engines.

Instead of the usual number of ordinary boilers, some of which are, during nearly all the working hours, doing duty at an uneconomical load, while others have to be kept fired up in a state of readiness, that are required for supplying sufficient steam to cope, not only with the average, but the maximum, demand, Mr. Halpin proposes to reduce their number to such an extent that those left shall be constantly at work at their most economical load during the 24 hours, that is to say, that their total capacity per day (of 24 hours) shall be slightly in excess of the total demand for steam during the hours of working.

A sufficient number of thermal storage reservoirs, which are to be vertical cylinders, egg-ended, 30 x 8 ft., are connected to the reduced number of generating boilers, and nearly full of water, sufficient space being left at the tops to allow of ample steam-generating space, the boilers themselves being full. A necessary condition to the maintenance of an efficient storage, and to keep this plant as small as possible, is that the pressure in the generating boilers and the receivers should be considerably higher than that at which the engines are to work, the pressures proposed being 250 and 130 lbs., respectively. The steam supplied is drawn off from a steam receiver connecting all the reservoirs, and passes through a reducing valve. The action is then as follow: The water in the generating boilers is heated and circulated round the system up to such a temperature as accords with 250 lbs. pressure (406° Fahr.). The engines then, as already mentioned, are supplied direct from the reservoirs, and at times of small demand, below the average, heat is stored in the reservoirs; while at times of large demand, above the average, steam can be drawn away from the reservoirs at any rate desired, which, as it is drawn off, relieves the pressure to which the heated stored water is subjected; the latter concurrently flashes into steam and keeps up the supply. It is proposed to keep the level of the water in the reservoirs as constant as possible, but during periods of heavy loads and large demand it is allowed to fall, being made up again during periods of small demand. The feed water is pumped into the reservoirs where all

sediment is deposited, as hot as possible; by this means the boilers always work on clean water, which greatly enhances their efficiency and life.

The practical efficiency of this system has yet to be proved, the great question being the regulating and insuring of proper circulation of water, which, when the number of storage reservoirs containing it are greater than the number of the generating boilers supplying them, causes such an increase in the difficulties that on this particular point the whole success must depend. In other respects, one can venture to prophesy satisfactory results.

When hoisting machinery, such as isolated cranes, lifts, etc., is used, it is necessary to economy that they should be constantly at work, or else a considerable loss must take place in the combustion of fuel during the periods of light load or small demands already alluded to.

Where a large plant, however, such as is generally used at all docks of importance, and where a large proportion of the cranes could be relied upon to be working simultaneously, steam can be economically supplied from a central battery if other and disturbing conditions do not arise, such as:

(*a*) The difficulty of connecting the cranes to the main steam pipes, at the different points required for service, where such cranes are to be movable along, for instance, the side of a quay.

(*b*) Risks of sudden and complete stoppage of the whole of the plant, and danger to human life in case of the bursting of a main.

(*c*) The loss entailed by reason of the expense and difficulty of returning the exhaust steam to the boilers, or else allowing it to escape into the atmosphere.

The author is aware that this question of supplying steam over an extended area has been successfully accomplished by the steam supply of New York; but here, as far as he knows, the spent steam and condensed water is caused to flow back again to the generating station, where it is no doubt easily returned to the boilers. Where, however, the steam supply is to be used for motive-power purposes, it would be necessary to condense the steam at the generating station on its return, so as not to throw a back pressure on the consumer's engines,

thus necessitating increased plant and working expenses. For driving shop or yard travelers, this system of central steam supply is not applicable, on account of the difficulties referred to in the way of connections of machines to steam pipes while allowing for their traveling.

With regard to efficiency, it appears from the comparison of different steam cranes and hoisting machines that about 1.1 to 1.4 lbs. of steam, on the average, are utilized in the cylinders (at 60 lbs. boiler pressure) in small and large cranes, respectively, for every horse-power of work done on the weight lifted, and taking the evaporation of water per pound of coal in the case of a central supply battery at 9 lbs. and in self-contained power machines as about 7 lbs., the figures work out as follows: In plant supplied from central battery 7.33 lbs. of coal are required per hour per horse-power done on the weight, and in self-contained machines, 9.4 pounds.

To test the actual cost on a large practical scale, the author, through the kindness of some friends at an important coal station in London, has been enabled by a three-days' trial to determine that the cost of lifting coal from the holds of vessels lying alongside on to the wharf to be 1¼d. per ton. This includes craneman's wages, cost of cranes (taking their life at 20 years), coal, oil, waste, water and repairs.

For large concrete block-setting machines, generally known as "Titans," or for yard travelers, contractors' cranes, excavators and such tools, machines with self-contained engines and boilers would no doubt prove the most serviceable.

In steam-hoisting machinery there are, necessarily, a large number of working parts, both in the engines and the machines proper, including the various shafts, gears, clutches or cones for putting the different motions in and out of action. These not only give rise to much rattle, wear and tear, but necessitate a heavy amount of upkeep and require the attention of an experienced driver, who also has to attend closely to the boiler firing and feeding, while undivided attention should be given to the work in progress.

Hydraulic Power.—As in the case of steam, to use this power economically it is also necessary that all the plant supplied from one central station should be regularly at work, and that the average demand for power-water should bear a high proportion to the maximum that the plant is designed for; otherwise the losses in fuel, steam and general

working expenses at periods of small demand will exist. These losses, however, can be effectually prevented in certain cases, where, instead of obtaining the pressure-water by passing it through accumulators, circumstances permit the use of a storage reservoir, placed at the required height, to give the desired pressure, and of such a capacity as to contain a supply for at least 24 hours' working. This, neglecting pipe friction, would be 1 613 ft., to give an effective pressure of 700 lbs. per square inch. In this case, under such conditions, the pumping plant would only have to be of sufficient daily capacity as the average required by the working plant spread over the 24 hours.

Where plants, however, take the form of a public service, such as exist in London, Hull, Birmingham, Liverpool, Manchester, and some of the chief cities in Australia, and where, by the multiplicity of uses to which the power is applied, the average demand in such cases becomes fairly constant during known periods, the daily consumption is proportioned somewhat as follows : From 6 to 8 A. M., when the artisan class commence working, warehouses and loading and unloading stations are the chief users ; from 9 to 12, full demand takes place, by the continuance of this class of work plus that required for passenger lifts for offices, etc. ; there is then a lull during the lunch or dinner hour, and from 2 till 5 or 6, when the warehouses close, there is again the full demand. After this another special requirement takes place, in the use of lifts in hotels, clubs, chambers, residential mansions, etc., giving a gradually lowering load until midnight, when the minimum takes place until 6 A.M. And so, by the use of a constant daily diagram, which can be taken and recorded, it becomes possible for the officer in charge of the central station to regulate the firing of the boilers and generation of the steam-power, and thus a fairly good efficiency and economical working of the plant can be obtained even where the water pressure is obtained by passing it through accumulators.

There is no doubt that hydraulic power is peculiarly adapted for all kinds of lifting purposes, the working of presses of all types, and last, but not least, as a means of obtaining powerful jets of water for the extinction of fires.

The action of the water in the hydraulic cylinders, viz., the moving of the rams in a rectilineal direction, renders this power the most direct of all others, as all hoisting machinery has obviously to move

weights straight up and down, and all rotary motion, with the constant reduction in speed and the consequent wear on rapidly moving parts, can be dispensed with. The expression "rapidly moving" is used advisedly, as in almost all cases the prime revolving motor, to be within reasonable proportions, has to be made to work at a relatively high speed. With regard to wear of hydraulic machines, the friction of the rams in the glands is almost infinitesimal; the only parts subject to much work and abrasion are the chains or ropes and the axles of the pulleys over which they pass. This, also, is very small, owing to their slow speed of rotation.

One great disturbing element to the proportioning of the supply of water-power to the work to be done, always more or less exists in hydraulic machinery, and is due to the fact that water is non-compressible and non-expansive, the result being that the same quantity of water is used, whether the load lifted is great or small, and, in the case of hydraulic engines, that there is difficulty in regulating the strokes to the work required to be done.

In this branch of mechanical engineering, however, some success has been arrived at in overcoming these objections.

With regard to lifts, instead of having only one hydraulic ram or jigger for working hoists or suspended lifts, or only one ram or cylinder for the direct-acting lift, several actuating rams are supplied, attached to a common crosshead, and which can either be worked separately, combined, opposed or collectively; and by admitting the water to them in either of the ways just mentioned, it will be seen that any desired power can be obtained, the regulation of the admission of water to any or all of these cylinders being controlled by a supplementary valve called a power-setting valve, in addition to the ordinary starting valve. In this case the attendant has only one starting valve to operate, and on his opening the passage for the water it flows to the cylinders first through the power-setting valve, which latter, being hydraulically pressed forward, keeps on moving to greater and greater powers by giving access to further cylinders, until the lift rising has attained a certain prescribed speed, when the power-setting valve is locked by a pawl worked by a governor, and the lift goes on rising at the correctly proportioned power. When the lift stops, the governor drops, the pawl is released, and the power-setting valve returns to its normal position. Even with this arrangement, however, an exact proportioning of water used, to

work done, is obtained only occasionally, when the weight happens to fit in. Of course, the greater the number of powers, the closer the approximation. The saving effected by this type of hoist or lift is stated to be considerable, and from experiments that have been made between an ordinary jigger lift and a similar one fitted with the differential cylinders, the following figures were obtained:

	Number of days at work.	Number of trips made.	Gallons of water used.	Gallons per trip.	Gallons per passenger.
Ordinary jigger lift.....	275	54 493	393 400	7.22	3.8
New jigger lift	134	27 291	80 700	2.95	1.47

The saving being 57.9 per cent.

In the best designs of hydraulic cranes, when fully loaded and under favorable conditions as to working, the total efficiency is about 60 to 70%, while in direct-acting hoists, that is to say, where only one ram is used, this would rise to about 80%, which represents on the average about 35 lbs. or 3½ galls. of water for every horse-power of work done on the weight lifted. This referred to the consumption of coal at the central station means 4.5 to 5 lbs. per horse-power in weight lifted by the machine.

With regard to cranes or travelers, this principle of varying the power automatically to suit the weight cannot be applied so easily owing to the fact that in this class of machine it never starts in motion with the full load, and a certain amount of movement has to be made to pull up the slack chain or rope, which, in the case of a power-setting valve, would take up a position of a lower power than that required when the power came on. But still the power-setting valve or its substitute could be controlled by hand, the drawback to this being that the operator would in all probability, to save himself trouble, go at once to the highest power.

Referring to hydraulic engines, Mr. A. Rigg, of London, has made a special type known as a revolving engine, in contradistinction to a rotary. By his system the stroke of the pistons in the cylinders are variable and proportioned automatically to the work to be done, the means of doing this being as follows: Three or four pistons are each pivoted equidistant apart to the inside of a ring forming a fly-wheel, while the cylinders in which they work are pivoted round a common

center piece forming a steam chest and valve chamber, their center being capable of lateral movement along a line passing through the center of the fly-wheel and controlled by the governor; from this it will be seen that when the two centers coincide, no relative movement of pistons and cylinders takes place while when displaced, rotation will take place in either direction according to which side of the fly-wheel center they are situated, and the power given out will be proportional to the amount of eccentricity of the cylinder pivot.

This engine does not appear to have been appreciated as its merits deserve, but the author believes that they could do good, economical and valuable work. Several are in daily use working capstans, pumping, and even driving dynamos.

Electricity.—With regard to the use of this still mysterious agent as a motive power for lifting purposes, a fair amount of work has been done of late years, not only by manufacturing electricians, but by mechanical manufacturing engineers particularly, and the author has had the advantage of making tests with some of them. The remarks relating to the necessity of the plant being regularly at work, etc., apply to the use of electricity as well as of steam and water, for although the nature of the dynamo machine is such that the electrical output regulates itself in accordance with the demand, yet the prime mover (the boiler) still gives rise to the difficulties of regulating the fuel and steam generated. The use of secondary batteries gets over this trouble to a great extent, and they are used chiefly in connection with the public electric-light installations, where continuous currents are used; but this, of course, entails an increased initial outlay and about 12 to 18% for depreciation. It appears, so far, that electricity can be applied, and made to work all the known kinds of hoisting machinery; but whether it can ever compete successfully with hydraulic power for general use still remains to be proved. In case of hoisting machinery, such as lifts, there is no doubt that the direct-acting ones are far preferable to those that are electrically worked. In Victoria Mansions, Westminster, London, where the author's offices are situated, there are several hydraulic lifts, and two of them have lately been fitted with an independent accumulator and a set of three-throw pumps, the latter worked by an electric motor. By this means the power-water is, after passing through the cylinders, returned to a tank and used over and over again. The motor is compound wound and drives on to a worm wheel, the

end thrust of the worm shaft being taken by a series of small hard-steel balls working between two hard-steel grooved rings, which system the author first suggested in 1889. The total efficiency of the combined machines, that is to say, the proportion between the horse-power in the water pumped and the horse-power absorbed by the motors is over 50%, and, as far as time has permitted a judgment to be made, the arrangement is giving satisfactory results. The switching on and off of the currents are controlled by the rise and fall of the accumulator weights. This system might find suitable applications in other cases, but would have to be governed by the price of water.

With regard to working cranes or travelers by electricity, both shunt and compound wound motors are used; but the advantages lie chiefly with the latter, as, by using that system of winding, a uniform speed of motor is obtained irrespective of the weight lifted, and again it enables the machine to be stopped and started with the load on. For engineering shops, foundries, setting of concrete blocks, etc., this, of course, is of primary importance, and it will be found best to have separate motors for each movement, such as lifting, traveling and racking, as not only is mechanical gear saved, but it gives the driver easy and undivided control of each movement, leaving his whole attention to be devoted to the object lifted. The mechanical construction of the cranes or travelers can, of course, be made of any type, for instance:

(*a*) When one motor only is used on a traveler it can be made to drive a transverse endless rope passing over and under a series of pulleys and jockey pulleys attached to the crab frame, the said pulleys actuating the various movements either by clutches or open and crossed bands.

(*b*) Or where a separate motor is used to work each movement, if compound wound, would be rigidly attached to one of the spur pinions in connection with the respective gears.

(*c*) Another system would be to attach the motor to the traveling crab, which would save some friction in the way of driving it from one end.

In the case of cranes the motors are generally made to work direct on to a worm, the wheel being on the drum shaft or directly geared to it, or the shaft of the armature may be fitted with a pulley with a slightly hard but compressible face and pressed against the face of another driving pulley geared to the barrel, and so driving by friction.

The most recent electric cranes that have been put up in England are those at Southampton, the frame-work being made by Messrs. Stothert & Pitt, and the electrical portions by Messrs. J. G. Statter & Company. These cranes are very much on the lines of those supplied to the Hamburg docks and manufactured by Messrs. Siemens & Halske, of Berlin, but, as they contain some novel features, the author ventures to describe them somewhat in detail.

The cranes are supported on a traveling gantry having but one vertical end, viz., double frame, carried on four wheels running on two lines of rails. The other end of the gantry terminates horizontally and is supported on an overhead rail on a pair of wheels, but geared with the former. This arrangement admits of the greatest clear space under the cranes, which is necessary in order not to obstruct the passage of locomotives or trucks on the railway which runs under the gantry. Each crane and its frame weighs about 35 tons and is capable of being easily moved along by hand gear, in order to plumb the holds of any vessel it may be handling. The cranes are arranged to lift at 200 ft. per minute and to slew at 400 ft. per minute, and the maximum duty of each crane is 3 tons. The radius of the jibs is 27 ft. 6 ins.

There are two "Statter" motors, the one for lifting, absorbing 200 volts and 220 ampères, making 600 revolutions per minute. It runs continuously and drives a worm and worm wheel. The worm wheel is put into gear with the barrel by means of a "Lindsey" transmitter. Switch gear is provided for stopping, starting and reversing this motor, as required. The slewing motor has a capacity of 50 ampères at 200 volts and makes 1 000 revolutions per minute. It drives by means of a worm and worm wheel, a pinion, gearing into a circular-toothed rack. This motor is stopped, started and reversed, and is always in gear. Suitable slipping clutches are provided between motor and worm gear in both cases. A powerful foot brake is also provided. In addition there is a magnetic brake, which comes into operation and holds the load in case of failure of the supply of current to the crane.

The current is supplied to the cranes in question by the Southampton Electric Light Company, which has laid down a special main from its station to the switch-house at the head of the quay. From this point the crane mains are carried, and consist at present of copper of .25 sq. in. section, capable of extension to 1.25 sq. ins. These are run in a concrete culvert down part of the quay and in a wooden culvert

pitched inside and outside, underneath the timber framing of the quay. At the cranes these mains deliver the current through insulated cable ends to two overhead conductors of silicon-bronze wire. Two clamping blocks are arranged under the gantry to each crane, one to take the positive and the other the negative line. These are clamped by a screw and hand wheel, combined with a stop gear which locks the wheels of the crane gantry when the leads are clamped, and obliges the driver to unclamp his conductor before attempting to move the crane. When the conductors are unclamped, the current is supplied to the crane by the dead weight of the conductors resting in the lower half of the clamps. The current is led from these clamping blocks in a special heavy grooved hard-wood channel to the center pivot of the crane. This pivot is of steel 6 ins. in diameter, bored with a 2-in. hole through which the leads pass. On the head of the crane pin a pair of collector pins are fixed, and from them the current is led to the switchboard. The switchboard fixed in the cabin contains the ampère meter, main switches and fuses for lifting and slewing motors, together with switches for six lamps which are employed to light the crane cabin and to throw light upon the loads. The lamps for the latter duty are fixed in a reflector similar to the system of reflector used in the Naval and Mercantile Marine. Each reflector is attached to the jib. From this switchboard, the current for the lifting and slewing motors is led to special lever switches which grade the supply of current and consequently the torque and speed of the motors. The working surfaces of the switches are built of a special commutator metal insulated by mica. The switches combine in one a regulating and reversing switch. With the lever vertical, the current is off the motor; when forward, it causes in the case of the slewing motor a slew to the left hand, and when backwards, a slew to the right. The slewing may be performed at a very slow speed or at the full 400 ft. per minute, according to the extent to which the lever is pulled over from the vertical. The sparking is taken at two carbon points. There is no sparking on the contact plates. Steel wire rope is used for the lifting. The cranes have been tested by lifting their full load in the presence of the Harbor Committee and their engineer.*

* These cranes weigh 35 tons, and the price is £1 450, while for hydraulic ones of the same capacity on arched platforms to span railway underneath, the weight would be 28 tons and the price, £750.

The tests alluded to by the author were carried out with the view of determining the following :

First.—E. H. P. absorbed by the motor when lifting the chain and hook with no load, so as to determine the friction of the machine.

Second.—E. H. P. absorbed when lifting known weights at known speeds.

Third.—Energy in horse-power put into the weight lifted.

Fourth.—The efficiency of the machine.

Fifth.—E. H. P. absorbed by motor when lowering the load.

Sixth.—E. H. P. absorbed when traveling and lifting.

Seventh.—E. H. P. absorbed when traveling and lowering.

1st Test.—Single 8-H. P. motor, shunt wound, driving a traveler by means of endless gut rope and crossed and open bands, as previously described, 80-volt circuit.

When lifting chain, block and hook, 6 E. H. P.; when lifting 6 tons at 2 ft. a minute, the E. H. P. was 7.6 and the actual horse-power in weight, 1.04; when lifting 1.7 tons at 18¾ ft. a minute, the E. H. P. was 10.5 and the actual horse-power in weight, 2.2; efficiency of machine at 6 tons, 13.5%; efficiency of machine at 1.7 tons, 21 per cent.

2d Test.—Single 8-H. P. motor, shunt wound, working a traveler, driving and traveling by a transverse shaft with compressed paper friction cones at each end, driving two cross shafts by means of being pressed against chilled-iron coned discs, 100–105-volt circuit.

When lifting light, 1.77 E. H. P.; when lifting 7 tons at 7 ft. a minute, 5.75 E. H. P.; energy in horse-power put into weight, 3.32; efficiency of machine, 57.7 per cent.

3d Test.—This was an ordinary hand-power foundry traveler, converted for working electrically, and was driven by one single motor at one end, all the other motions being taken off one transverse shaft.

When lifting light (quick speed), 2.83 E. H. P.; when lifting light (slow speed), 2.4 E. H. P.; when lifting 4 tons at 8.9 ft. a minute, the E. H. P. was 7.73, and actual horse-power in weight, 2.42; when lifting 4 tons at 3.4 ft. a minute the E. H. P. was 5.0 and the actual horse-power in weight, .9; when lifting 9, 13.5 and 18.5 tons at 3 ft. a minute, the E. H. P. were 6.8, 9.6, 9.9, while the actual horse-powers in weight were 2, 3 and 3.7; the efficiency of the machines in the above cases varied from 29.05 to 37.5 per cent.

4th Test.—Southampton cranes.

When lifting light, 4.01 E. H. P.; when lifting .75 ton at 200 ft. a minute, the E. H. P. was 25.16, while the actual horse-power in weight was 10.17; when lifting 1 ton at 200 ft. a minute, the E. H. P. was 31.68, while the actual horse-power in weight was 13.57; when lifting 1.2 tons at 200 ft. a minute, the E. H. P. was 36.86, while the actual horse-power in weight was 16.29; when lifting 1.5 tons at 200 ft. a minute, the E. H. P. was 42.02, while the actual horse-power in weight was 20.35; efficiency of machine when lifting the different weights was 40.4, 42.8, 44.1, 48.4%; when slewing at full speed 1.86 E. H. P. was consumed.

In all the above cases, if the E. H. P. used when lifting light be deducted from the E. H. P. when lifting loads, the net efficiency attributable to doing work is good, viz., 65 and 49% in the first case, 71.7% in the second case, 50% in the third case, and 53% in the last one, thus pointing to the direction in which further efficiencies could be obtained.

From this it will be seen the total efficiency of the machines in tests Nos. 1 and 3 is not high, the worst result being No. 1, the loss of power in this case being evidently due to the necessity for a large amount of gearing when working such a machine from one high-speed motor.

A full table of the above-described tests is given in Appendix No. I.

Some short time ago the author was called in by the Southampton Harbor Board to make a report on the question of supplying power cranes to their jetties and wharves, either on the steam or hydraulic system, and for the purpose of general comparison in the case of such an installation, he will now give the conclusions arrived at and supplement them by figures relating to an electric plant for doing the same work.

The installation at the outset was to have been only a small one, and comprised the following:

Hydraulic.—One pair of compound condensing engines and pressure pumps; accumulator; two boilers; six 30-cwt. cranes, with 30-ft. jib radius; two 20-cwt. luggage cranes, with 30-ft. jib radius; six large and 10 small capstans; pipes and connections, engine-house and shaft.

Steam.—Cranes, self contained, same as above; capstans, same as above; steam pipes, two capstan boiler-houses.

Electric.—Two pair of compound condensing engines and dynamos; two Lancashire boilers; cranes and capstans, same as above, but fitted with motors; mains.

The total cost of the various systems, including the engine-house and shaft, in the case of hydraulic and electric works, came out as given below; but it does not include the laying of hydraulic mains or the electric conductors, and it must be noted that the steam cranes are assumed to be self contained and not supplied from a battery of boilers:

Hydraulic, with engine-house	£13 561
Steam	11 120
Electric, with engine-house	11 736

The advantages and disadvantages of the several systems are summed up as follows:

Steam Advantages—(*a*) The first cost of installation is less than for hydraulic or electric plants.

(*b*) In the case of the cranes only, as they supply their own motive power, they cannot be affected by the failure of a main or the machinery at the power station, as in hydraulic or electric.

(*c*) The installation can be added to gradually at a less initial cost than with hydraulic or electric plants, where the power station should be sufficiently large for the maximum duty likely to be required from it.

Disadvantages.—(1) It is slow in action compared to hydraulic or electric power, working only at about half the speed.

(2) Each crane generating its own power, they are more costly to work than hydraulic or electric cranes, where one generating station supplies power for the whole plant.

(3) The drivers of the cranes have to be men of above the average intelligence and fairly good mechanics.

(4) The consumption of coal and fresh water is considerable, and if the cranes and capstans were not required to work, but kept in a state of readiness, more coal and water would be consumed than for the hydraulic or electric plant, if they were kept idle in a similar manner, there being so many more boilers to keep under fire, viz., one to each crane and one stationary one to each group of capstans.

(5) The cranes are noisy, and, owing to great speed, have much vibration, with consequent wear and tear entailing a high cost for repairs, and danger of fire as the boilers are liable to emit sparks with the smoke.

(6) Generally they require to be supplied with coal from a store,

entailing labor and creating dirt on the quay. The machinery is more complicated than hydraulic, and partly exposed to the weather, in addition to which its wear and tear is considerable, and there are possible risks of explosion.

(7) The cost of working is higher than hydraulic or electric.

Hydraulic—Advantages.—(*a*) The power for working the plant being generated at a central station, the cost of working is reduced to a minimum, there being only one set of boilers to fire, and practically no fresh water is required beyond a few gallons daily.

(*b*) The machinery is quick in action, at least twice the speed of steam, and speed for speed for lifting, compared with electric, has a much less wear and tear, the cranes being capable of working 60 lifts per hour, or more if desired. At the trial of the large hydraulic 35-cwt. cranes made for the Tilbury Docks, 81 working lifts were made in 47 minutes, in which the goods were lifted out of a boat, slewed round and landed on the quay.

(*c*) Only one driver and stoker is necessary; a lower and cheaper class of men can work the cranes and capstan than is the case in steam-driven ones. It is, however, necessary to have one skilled mechanic to generally look after the work.

(*d*) If the plant should be required to stand idle for any length of time, only a very small amount of fuel would be consumed.

(*e*) Generally the machinery is noiseless, simple, clean, all protected from the weather, and has not much wear and tear; the cranes can be easily moved along the quay.

(*f*) Besides the hydraulic power being used to work the machinery already referred to, it would be available for elevating purposes in neighboring warehouses and for the extinction of fires by means of injector hydrants.

(*g*) The cost of working is less than by steam, but about the same as by electricity, but the upkeep is less than either.

Disadvantages.—(1) The initial cost is greater than for steam and slightly more than for electric cranes.

(2) In the case of a breakdown at the power-generating station, or failure of the mains, all the plant would be temporarily stopped. Although the author mentions this, he does not consider it at all likely to occur, nor does he know of any case where this has taken place; it is only necessary to have all details made amply strong.

Electric—Advantages.—(*a*) The power for working the plant being generated at a central station, the cost of generating is reduced to a minimum, etc., the same as in hydraulic.

(*b*) Machinery is quick in action, though not quite so quick as hydraulic.

(*c*) Only one driver and stoker is necessary, etc., the same as in a hydraulic plant.

(*d*) If the plant should be required to stand idle, etc., the cost is the same as for a hydraulic plant.

(*e*) Generally the machinery is fairly noiseless; it is cleaner than either steam and hydraulic, and can easily be arranged to be self-propelling along the quays.

(*f*) The power can also be used for lifting purposes in neighboring warehouses.

Electric—Disadvantages.—(1) Speed for speed of lifting, there would be more wear and tear than in the hydraulic system.

(2) In case of breakdown at the power-generating station or the failure of a main, all the plant would be temporarily stopped.

(3) The drivers of the cranes would have to be men of above the average intelligence.

(4) The upkeep would be slightly more than in the case of a hydraulic plant.

With regard to the cost of working the above systems, the author estimates them as follows:

APPROXIMATE ESTIMATE AFFECTING THE COST OF WORKING.

	Hydraulic and Electric.	Steam.
Coal for capstans, presuming steam in boilers is kept up all day and capstans ordinarily at work.	.....	20 to 25 cwt.
Coal consumed per day of 10 hours when working eight cranes continuously.	35 to 40 cwt. The greater would probably include the use of capstans.	70 to 80 cwt.
Water (fresh) consumed per day of 10 hours when working eight cranes continuously.	Practically *nil*.....	4 600 gallons.
Coal consumed when machinery standing idle and steam in boilers kept up.	1 cwt. per hour.....	½ cwt. per hour each crane, and ½ cwt per hour each capstan boiler.

From a general consideration of the above statements, it appears

from the author's point of view, that for a system such as is assumed, hydraulic would be the most suitable.

In connection with hoisting machinery and the motive power for working it, steam engines have now reached such a state of perfection that little more improvement in their designing and construction appears possible. Electric dynamos and motors can be made to reach 95% efficiency, so but little remains to economize upon here. The only remaining power dealt with in this paper is hydraulic, and in this room does exist for economizing the actuating water, and much should be possible in making further and enhanced economies. When a load is moved at a constant level and not against gravity, obviously no power would be required except for overcoming friction. Again, if it could be possible to so arrange the machinery and the work, that all loads should restore the water on which they descend into a reservoir, that is to say, should force the exhaust water previously used in the hydraulic cylinders as power-water into a reservoir, where it would be subjected to yielding pressure or utilized to assist the steam engines in pumping, it will be seen that a great gain would be possible. For example, say, in the case of a lift or jigger, if the same load was lifted as was lowered, no water should be used beyond that required for overcoming the friction of the machines and a method of working analogous to a regenerating system would be established.

This suggestion the author ventures to throw out for the consideration of engineers interested in this branch of mechanical science, and because he considers the present time so opportune for the inauguration of hydraulic power supplies in the several large cities in this great republic, and none more ripe and suitable than this vast one in which representatives from all parts of the world are now congregated. When buildings exist, as they do in Chicago, of such enormous elevation —the Rookery and Auditorium, as examples which by their height almost preclude the likelihood of their occupants and visitors walking down—much the same weight could be relied upon to be lowered as is raised, and the gain to be derived is at once evident.

For the purpose of supplying motive power to a city such as this hydraulic power is eminently suitable, as it could be used for passenger and goods lifts, and hoists for various pressing operations, the working of charging and discharging cranes along the large river frontage, for working the swing bridges, coal tips, railroad-crossing gates, grain elevators,

hydraulic riveting, raising and lowering of theater fireproof curtains, and would be available generally wherever mechanical motive power is required. When extremely high pressures should be necessary, a simple, well-known form of mechanism known as an "intensifier" gives the ready means of raising it to any amount. Lastly, and far from least, is the ready means the hydraulic system gives for the extinction of fires. In the face of all these advantages, the author suggests that this power would be the right and fit one for the particular purpose under review.

The London Power Company is allowed to draw 500 000 galls. daily from the River Thames free, on condition of returning it through the sewers, so flushing them. This is an extremely important point, and for flushing the sewers of this or other important cities during long spells of dry weather cannot be overrated.

One great advantage in the use of water supplied from a central station is, that the greater the demand, the better is the pressure maintained in the mains, and over 50% of the power at the generating station would be effective in work done on the consumer's premises. The author knows of a case where steam-power has been dispensed with (for pumping water for working lifts) and the public hydraulic power substituted, with a saving of 30% in the cost of working, and if this had been adopted at the outset the economy would have been greater.

Some objections may be raised that the water would be liable to freeze in very cold weather, but if the mains are laid well below the surface and covered, all buildings being heated in the winter, the author does not think any trouble would arise. Pressure raises the temperature of the freezing point. Apart from this, if desired, salt water could be used, and, as an actual case in point, the Barcelona Power Supply is all salt water.

Steam is out of the question as the motive power for such a case as is now being referred to, and electricity does not give facilities for adapting it to the multifarious processes alluded to, and, instead of being an aid in extinguishing fires, would rather tend to increase them, although certain advantages would exist in being able to work electric fire engines from electric mains which never require firing up and are always ready.

For occasional users of intermittent motive power, water, although at first glance it might not be considered suitable, would in practice be

found to be so, and to be very economical, particularly with motors such as the Rigg engine, or even what is known as the Armstrong type. The space occupied by the motors would be small, the speed slow, the wear and tear very small, and they would require no skilled attendant; besides being safe, no risks would exist of shocks, of explosions, and consequent loss of life. Of course, electricity would serve equally well as a motive power, and the hydraulic power is not put forward as a more suitable one, but simply to show that it could be used with many advantages over electricity, and certainly with more applications for its use. Probably if motive power was the chief public requirement, it would pay to install an electric service in addition to the hydraulic, as there would be room for both; and if qualified experts were called in to advise thereon, there is no doubt but that the right power would be apportioned to the right duty. For central supply stations, the motive power should be subdivided into small units, say, 150 to 200 H. P., depending on the size of the station and the fluctuation in the demand, and the engines should be of the vertical inverted triple-expansion condensing type; they give less wear and tear, and such as there is, is more even. Although not forming a part of the subject of this paper, to prevent misunderstanding the author would point out that the fire-extinguishing facilities given by a service of hydraulic power are not obtained by a wasteful expenditure of water, for the injector hydrants referred to act on the injector principle, viz., a very small jet of high-pressure water injected into the center of a large jet drawn from the public service mains increases the quantity so drawn, and intensifies the pressure of the latter on the delivery side of the injector so as to throw a jet equal to that of any fire engine.

As showing the cost of installing the hydraulic system in such a city as Chicago, the author now gives an estimate (based on English prices) for the plant, including buildings and 15 miles of mains.

Machinery.—Three sets of triple-expansion inverted steam surface condensing engines, with pressure pumps attached, each capable of pumping 150 000 gallons per day of 12 hours, against a pressure of 750 lbs. per square inch.

Four sets of three-throw pumps for raising the water into the settling and storage tanks having, for safety, 10% more capacity than the pressure pumps.

Six accumulators, three for station, three distributed; settling and

storage tanks; decanting pipes; 10 filters; air vessels; traveler; 3 tubular boilers; economizer; 8, 6, 5 and 4 in. pipe mains with valves.

Erecting the above and putting up engine buildings, chimney shafts and town accumulator houses.

Total cost ..... £66 000.

To double the plant would add only about 60% of the cost.

The above figures do not include the cost of laying the mains, but the author states that this in English prices work out as under:

Eight-inch pipes per yard run, 17s. 6d.; 6-in., 15s.; 5-in., 13s. 9d.; 4-in., 12s. 6d

The actual cost of working the plant he estimates as follows:

Works—

1 engineer at	£3	0 0	per week.
2 engine drivers at £2	4	0 0	"
2 stokers at 26s.	2	12 0	"
3 laborers at 22s.	3	6 0	"
Total	12	18 0	"
Say, 52 weeks at £13, per annum			£676 0 0

Coals—

For working the engines 24 hours per day, developing an average of 125 I. H. P.; 2.24 lbs. of coal per I. H. P. per hour = 3 tons, 300 days, 900 tons at 15s	674 0 0
Stores	100 0 0
	£1 450 0 0

APPENDIX No. 1.

TABLE OF RESULTS OF TESTS ON ELECTRIC HOISTING MACHINERY.

NUMBER OF TESTS.	Current supplied. Volts.	Current supplied. Ampères.	Counter E. M. F.	Effective volts.	Watts consumed	Weight lifted in tons.	Speed in feet per minute.	Horse-power in work done on weight.	E. H. P.	Efficiency of machine. Percent.	REMARKS.
No. 1.	74	61	1.8361	73.1639	4462.99	.....	.....	.....	5.98	.....	Lifting light (chain and hook only).
Shop traveler.....	74	80	2.408	71.592	5727.36	6	2.09	1.094	7.67	13.5	Lifting weight.
	74	110	3.3110	70.689	7775.79	1.7	18.75	2.163	10.42	20·75	Lifting weight.
	75	111	3.3411	71.659	7954.14	1.7	19.62	2.264	10.66	21.23	Lifting weight.
	76	55	1.6555	74.3445	4080.95	6	.....	.....	5.47	.....	Lowering.
Single motor.....	70	95	2.8595	67.1405	6378.35	6	.....	.....	8.55	.....	Traveling and lifting.
Shunt wound driving by band and belts.....	77	65	1.9565	75.0435	4877.83	6	.....	.....	6.54	.....	Traveling and lowering.
	79	63	1.9565	77.0435	5007.83	1.7	.....	.....	8.05	.....	Traveling and lifting.
	85	37	1.1137	83.8863	3103.79	1.7	.....	.....	4.16	.....	Traveling and lowering.
No. 2.	103	13.25	3.1	99.9	1323·67	.....	.....	.....	1.77	.....	Lifting light (chains and hook only).
Shop traveler.....	103	43.0	3.1	99.9	4295.7	7	7	3.326	5.76	57.7	Lifting weight.
	103	18.0	3.1	99.9	1798.2	7	.....	.....	2.41	.....	Lowering weight.
Single shunt wound motor...	103	8.4	3.1	99.9	839.2	.....	.....	.....	1.12	.....	Quite light, driving cones only.
	103	18.0	3.1	99.9	1798.2	.....	.....	.....	2.41	.....	Racking light.
	103	23.0	3.1	99.9	2297.7	7	.....	.....	3.08	.....	Racking loaded.
	103	18.0	3.1	.....	1798.2	.....	.....	.....	2.41	.....	Traveling light.
	103	23.0	3.1	99.9	2297.7	7	.....	.....	3.08	.....	Traveling loaded.
No. 3.											
Foundry hand traveler.....	110	22	.....	.....	2110.0	.....	9.92	.....	2.83	.....	Lifting light (quick chain and hook only).
	103	20	.....	.....	1795.0	.....	3.41	.....	2.4	.....	Lifting light (slow chain and hook only).
(Converted) one-motor compound wound driving cross shaft by spur gearing...	90	76	.....	.....	5765.0	4	8.92	2.42	7.73	31.3	Lifting weights (quick).
	115	38	.....	.....	3782.0	4	3.41	.92	5 07	18.1	Lifting weights (slow).
	103	58	.....	.....	5109.0	9	3.27	1.99	6.85	29.05	Lifting weights.
	115	73	.....	.....	7150.0	13.5	3.32	3.04	9.59	31.7	Lifting weights.
	98	86	.....	.....	7091.0	18.5	2.97	3.73	9.95	37.5	Lifting weights.
No. 4.	200	15	.397	199.621	2994.31	.....	.....	.....	4.01	.....	Lifting light (ropes and hook only).
Southampton	200	95	2.403	197.597	18771.71	.75	200	10.17	25.16	40.4	Lifting weight.
	200	120	3.036	196.964	23635.68	1.0	200	13.57	31 68	42.8	Lifting weight.
Cranes.	200	140	3.542	196.458	27504.12	1.2	200	16.29	36.86	44.1	Lifting weight.
	200	160	4.048	195.952	31352.32	1.5	200	20.35	42.02	48.4	Lifting weight.
	200	7	1.498	198.502	1389.51	.....	.....	.....	1.86	.....	Slewing.

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PRACTICAL AND ÆSTHETIC PRINCIPLES FOR THE LAYING OUT OF CITIES.

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The laying out of cities is accomplished in two ways: either in the course of additions to an existing settlement, by gradually extending the present roads and occasionally establishing new roads, as the number of buildings without reference to one another is increased; or, by establishing a general plan for new cities or parts thereof, according to which the intended construction is to be realized. The first way has been called the natural, and the last the artificial, method of laying out cities. This is a false definition, for it does not answer

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the natural purpose to let the buildings string themselves together, regardless of plan; and it is not an artificial acquiescence, but practically a confirmed necessity, that the laying out or spreading out of a city should proceed upon the basis of a well-considered, comprehensive plan. It is more correct, therefore, to call the first method of city building the arbitrary, and the last the systematic. We have here to do only with the systematic or regulated laying out of cities.

The essential basis of regulated city-building is the establishment of future streets and places, and, consequently, of the plans for them. Here we regard not so much the technical improvement of the streets, or street-building proper, but rather a very skillful, consistent connection and complete network of streets, requisite for the traffic and growth of the city, the residence and joint life of the citizens. We are constrained, therefore, to develop the mere street plan into a building plan, or, further, into a city plan, *i. e.*, a design in which, out of the network of streets and building areas, are arranged all those constructive regulations as well, which are demanded for the life of the city.

The practical principles of such a plan of city construction relate to traffic, to building and to health. Moreover, æsthetic principles are to be followed which concern the construction of streets and public squares and their relation to edifices.

I. Practical Principles.

a. Traffic.—The streets and squares of a city have first of all to fulfill the demand that they accommodate the city traffic in the most perfect manner possible, for to serve the traffic is their most important duty.

The designer of a city plan has therefore to ascertain and establish, first of all, the real lines of traffic of the present time and of the future, so far as they can be foreseen. The first of these traffic lines are everywhere those which lead from the middle point of the city to the outskirts and the rêverse. Their direction will be influenced by neighboring districts, railway stations, harbors, places of amusement and other attractive points of the vicinity. This gives rise to a net of radial lines or rays, as a glance at the map of an old city instantly teaches. The radial streets are on this account the first and most important in the design of a city plan to establish the members of the

network of city streets. They divide the city and suburbs into a series of sectors. As the size of these sectors increases toward the exterior, there arises the necessity of subdivision by means of radial lines of a second order, to the end that all the improved tracts may be conveniently reached from the midst of the city.

The second sort of traffic lines are such as serve the purpose of connecting the several sectors. They have in general a course like concentric circles around the central point of the city. These are the "ring streets," which are readily distinguished as of the first, second, or third order, etc., according to their signification on the city plan. In extended ground plans of a city the radial and ring streets often take on the form of longitudinal and cross streets.

Radial streets and ring streets always meet approximately perpendicularly. They divide the improved districts into lots of trapezoidal or approximately rectangular form. For obtaining proper building blocks a further division of these lots is necessary. These blocks are formed by using by streets which run approximately radial in one direction and circular in the other, so that the city plan will finally consist of a multitude of building blocks which altogether are more or less rectangular. Thus the traffic lines between two points which do not lie on the same street always consist of two legs at right angles to each other. From one extremity of the hypothenuse of a right-angled triangle to the other, one cannot go directly, but must always travel along the other two sides.

This does not correspond to the demands of traffic. The insertion of the hypothenuse is necessary, or, what is the same thing, the larger trapezoid or rectangular divisions must be traversed by diagonal streets before the subdivision by an approximately rectangular scheme of by streets is undertaken. The diagonal streets are to lie so that they will practically connect the chief focal points of the traffic directly with each other. These focal points are either given localities, such as railway stations, bridge terminals, landings, markets and the like, or they will be formed artificially by the junction of several streets. In the last instance occur the so-called "traffic places" as to which it is the problem to interpose an avenue from the one center of travel to the other.

The system of streets must be qualified to serve, not merely the ordinary foot, saddle and wagon travel, but in the design of the net-

work care should be taken that crowds may form in large numbers which street railways with animal or mechanical power may be able to take up.

The four kinds of streets, the radial, ring, diagonal and by streets, unless special reasons oppose, are so designed that existing roads and real-estate boundaries are followed if possible. This is only necessary for the existing highways comprehended in the built-up neighborhood; for other roads and property lines, the requirement is not essential.

The grades of the streets are to be made as convenient as possible for the traffic: the maximum to be according to local circumstances from 1 to 10%; the minimum, for the sake of drainage, 0.5 to 0.2 per cent. It is desirable that the streets should lie slightly above the general surface (say, 1 m.). Heights of 3 m. are ill-advised. Greater embankments and excavations are undesirable, because they increase the cost of improvements considerably, and require as a rule the grading of all adjoining property.

The width of streets should correspond to the expected traffic. It should be at least 10 m.; more than 40 m. is required only in the rarest instances. As to wider streets the claims of health and beauty give the proportions.

Transversely, the street is to be divided into at least one roadway and two raised sidewalks. A certain amount and kind of travel requires a special walk or promenade in the center of the street, a special bridle path or the division of the roadway for teams and equipages, giving rise to various cross-sections, and so much the more, when, for reasons of health and beauty, the streets are set out with rows of trees and flower beds.

Thus far we have considered only the traffic moving along city streets; but not less has the designer of city plans to regard those kinds of traffic which follow independent ways by, under, or over the city streets, viz.: Railroads (local and through), canals, wharves, docks, etc. Care should be taken to provide suitable space on the plan for the management of this sort of traffic adjoining the proper dépôts, harbors, landings and freight yards. To follow closely here the requisites of such a traffic-plan would exceed the bounds of the present problem, and would lead into technical domains which do not belong to city-building proper. Yet often it is a necessity to establish

the arrangements for the great traffic before the city map can be generally projected in detail.

b. The Buildings.—The meshes of the network of streets are as a rule termed the blocks. Their shape is rectangular, trapezoidal or triangular. The last form occurs especially along the diagonal streets. Various other shapes of blocks are occasionally found. The notion that acute-angled blocks are to be generally avoided on account of the difficulty of building on them, is incorrect; for, in the first place, conformity to the plan of traffic lines brings out sharp-angled blocks unconditionally, and, furthermore, the inconvenience in building is easily overcome, and indeed is availed of to bring about commercial and artistic advantages.

The sharp corners of the blocks are to be taken off. The amount to be cut off increases as the angle grows less, and should be large enough to provide for a façade on the corner. Instead of cutting away the corner it may be preferred to round it off; also, right-angled corners where a very large traffic occurs need to be cut off or rounded off. Generally, however, to accomplish this is neither necessary nor handsome. The cutting off of the obtuse angle of a block is only to be recommended in exceptional cases.

Within the blocks the boundary lines of the building lots should be drawn at right angles to the range lines of the streets bounding the same, so that in triangular, trapezoidal or irregular blocks buildings with oblique angles may occur only at street corners. Thus, oblique-angled property offers no difficulty in opposition to judicious and artistic building.

In case the lot lines are not perpendicular to the street, then, before building is allowed, the lines are to be so shifted by mutual exchange of equivalent areas that right-angled plots will everywhere obtain. If the change of lines cannot be obtained by the voluntary agreement of all owners, it becomes necessary to enforce the change by legal means, notwithstanding the opposition of individuals.

In right-angled blocks the depth is equal to the entire depth of two building lots abutting one another in the rear. Therefore the depth of lots, usual to the place or necessary for the future, fixes the depth of the blocks. Whatever the normal depth of a lot, the depth of the block is twice as great. In triangular or other blocks with diverging sides, the proportional depth is fixed by analogy with the foregoing.

The length of the blocks may amount to about 1½ to 2½ times their depth.

Factories and other industrial improvements require large blocks, say, 100 m. deep by 200 m. long, and should be so situated that the street and track connections with freight depots and harbors are easily obtained.

For private residences with gardens, medium-sized blocks are well adapted, say, 80 m. by 160 m. Property for rental and business houses which would be used as much as possible without gardens, may be judiciously divided into rather smaller blocks, say 60 m. by 120 m. Workmen's dwellings, finally, require smaller lots and, therefore, smaller blocks, say, 35 m. deep. The length can be increased to, say, 140 m. without disadvantage.

In dimensioning building blocks, however, there are to be considered the requirements, not merely of the individual, but in a greater degree of the public, that is, of the State, the parish and the corporation. Care is to be taken that blocks and parts of blocks be provided, suitable in position, shape and size for the erection of churches, high schools and common schools, for government buildings and courthouses, theaters, museums, concert and amusement halls, exchanges and banks, post and telegraph offices, markets and slaughter houses. If it is not possible for the city of the future to determine the size and place, collectively, of all the public improvements above mentioned, still the plan of the city should anticipate a sufficient number of building lots and blocks in convenient situations, which are proper to be used for public buildings as soon as the necessity arises. It is a mistake to refer the undertaking of such monumental and specific buildings haphazard to the later search anywhere for a half-way suitable place on a once-adopted building plan.

Many edifices, such as churches, theaters, museums, etc., require an open space, if not all around, at least on three sides. Many public buildings need a plaza even for traffic, while it is desirable to give others an axial position relative to the direction of a street, so that they may be readily found. All such claims are easily satisfied when laying out a plan of streets, but later only with difficulty and imperfectly.

c. Health.—Under the supposition that the climatic conditions of a country generally decide the settlement of a great mass of people in

one place, the first condition, in the interest of health, for the building or enlargement of a city is freedom from overflow and, therefore, a site above high water-mark, or a protection against flood. If the site is not free from overflow, protection must be brought about by artificial means, particularly by lowering the water surface, by raising the land surface, or by dikes with or without pumps.

A second condition is the dryness and cleanliness of the subsoil. It is important that the ground-water surface be not found in, nor occasionally rise into, those layers of sand which will be essentially changed or rendered impure in their condition under human settlement, and that, finally, the surface of the ground possess a form which renders an easy discharge of water possible. If the ground-water rises too high, it is prejudicial to health by inducing fermentation in the organic portions of the sandy stratum, prevents the use of cellar rooms, renders difficult the drainage of the surface and permits, through the absorption of waste material, the pollution, which is calculated to occasion danger to health, in water used for drinking and other purposes. In such cases before the soil upon a city plot is fit for use, the ground-water surface must be reduced, and its further rise prevented by a systematic subterranean canalization.

If the surface of the city ground generally shows a continual descent, the subterranean canalization can be, evidently, dispensed with for carrying off storm water. Here, however, as the city expands, the street gutters which have to carry off the rain water, require ever a larger cross-section; so, especially, the crossings of the streets with such gutters is very disturbing to the traffic, and so, for the draining of the surface, a network of subterranean channels soon proves to be necessary. Still, a gradual slope of the surface is important, because, in troughs and depressions of the ground without natural outlet, heavy rain storms may produce troublesome overflows notwithstanding the sewer system.

But, finally, the subterranean system of sewers is needful to carry off the domestic and industrial drainage and human waste material. As a rule, the combined system of sewers has shown itself the best for all three purposes described ; under certain circumstances, however, the arrangement of two or more separate sewer systems for ground-water, for rain, for house and industrial drainage, for fæcal deposits, may be judicious.

The general provision of good water for drinking, cooking and other uses is indispensable, as the subsoil of larger cities, even with the best endeavors to keep it pure, is undoubtedly incapable of furnishing drinking water. The combined provision of wholesome, faultless water is to be preferred to the separate provision of drinking water and water for other purposes.

The fourth requisite for health is light; not merely the diffused light of the atmosphere, but also the direct light of the sunbeam. For the distribution of light, the direction and width of the streets is limited by the height and kind of buildings. The north and south direction of streets is itself advantageous, because it brings the unimpeded sunbeams to front or rear of both rows of houses. But it has the disadvantage that upon the streets at right angles—that is, east and west—the front of one row of buildings and the rear of the other are entirely deprived of the direct rays of the sun. The practical view shows, however, in accordance with the scientific theory, that in a system of right-angled or approximately right-angled streets, not the directions of north, south, east and west, but those intermediate directions of southwest, northeast and northwest, southeast are most favorable to direct sunlight. Diagonal streets in such a street system have a very favorable position from north to south, but diagonal streets from east to west have a correspondingly unfavorable position.

In reality, however, the considerations of traffic and buildings allow the designer of a city plan so little liberty that the orientation of the streets with regard to the sun is but seldom of decided significance in the regulation of a network of streets. Furthermore, it is feasible in the arrangement of the buildings to have regard to the sunshine. The restriction as to height of buildings and number of stories, the sufficient regulation of larger building spaces, the arrangement of ground plans of buildings, and particularly of the sort of additions and wings so that no living-rooms, or as few as possible, may open their windows only on the north side; these are not in point to be further followed here; but if they will be duly considered in the requirements of the building police ordinances and in private building activity, it will be possible to shape dwellings satisfactorily in relation to sunshine, although the streets may not possess the most advantageous orientation.

Rooms without direct sunlight are, however, not to be altogether

avoided in general; they are even a necessity for certain industrial and artistic employments. For such rooms an abundant provision for diffused light of the atmosphere is so much the more important. This leads to the demand so to arrange the buildings that, at all events, in dwellings and other abodes, the rooms serving human needs may at least get a sight of a patch of sky under an angle of 45°. Thus, it may be guaranteed that the diffused rays of sunlight spread in the atmosphere will generally enter residences and living-rooms without being weakened and altered by reflection on the front of buildings or court-yard enclosures. But still this demand of not giving up the direct sunlight, which always presupposes that both in streets and in courts the height of buildings shall not practically exceed the distance between them, has thus far not been able to be realized in any city, through either the building directions of police or voluntary attention. In reference to this the effort has everywhere been, out of regard to cost, to enhance the usefulness of the building ground, in preference to studying hygiene. It is our duty, in the design of city building plans and building designs ever to bring into higher value the demands of public health with respect to supply of daylight.

For supplying the streets and buildings with artificial light by night, the illuminating gas, by reason of its consumption of oxygen and production of heat and of gases detrimental to health, does not wholly fulfill the hygienic requirement. The electric light, on this account, is to be preferred.

As a fifth hygienic requisite of city construction we have to denote care for the adequate amount of fresh air. And, indeed, there is needed a plentiful supply of air on the streets, in the blocks and within the buildings themselves. The aforesaid condition, that for the sake of light the height of buildings ought not practically to exceed the space between buildings, brings about on the streets and in the courts a sufficient airing. The streets and open courts, according to this, ought not to be less, or not materially less, than the houses are high; indeed, according to the customary height of houses, a breadth of free space of at least 10, 15 or 20 m. is necessary. For streets in the newer portions of a city this demand is easily realized; as for the courts, it is unfortunately frustrated in most cases by the value of the ground. But besides these most restricted dimensions of the air channels of a city, there are greater stores of air necessary, by the

help of which the change of air in the narrow channels can be consummated. Open squares serve this end, which interrupt the system of streets even at such places as the traffic alone does not call for; furthermore, blocks with interiors free from buildings, to contain gardens; and finally, districts of the city in which buildings will be allowed only with open spaces around them (country house districts) serve the same end. Such reservoirs of air can be formed by voluntary consent of property-owners; in default of which, they are to be provided compulsorily, by the official establishment of city-building plans, so that free plazas be kept open in the street system; that by retrograde building lines the interior of certain large blocks be kept free of buildings; and finally, that in designated parts of the city continuous rows of houses be interdicted.

In a particularly effective manner will the improvement of the air in the city be promoted by providing, on the established city plan, for a liberal setting out of trees. These serve, at the same time, a fifth hygienic interest, which consists in this—that the movement of the populace on pleasant shady paths will be made possible and easy. For setting out trees the streets and plazas are suitable, besides which care must be taken to provide for public gardens and parks and for promenades beyond them.

Streets with shade trees require a greater width than is necessary for traffic, or simply to provide light and air. The least width of a street planted with a row of trees on each sidewalk is about 20 m.; a width of 25 or 30 m. would be better. For planting a row of trees on a separate walk in the middle of the street a width of at least 25 m. is required; widths of 30 to 35 m. are better. Four or more rows of trees require still wider streets, so that the rows may be at least 6 m. apart. Instead of increasing the rows of trees it is often desirable to introduce front yards between the streets and buildings, or to lay out strips of garden plots with grass and ornamental shrubs within the street lines. It is self-evident that this sort of improvement is fit only for such parts of streets as can be dispensed with for traffic.

Just so the planting of open squares on the spaces which are required for traffic must not be demanded. Besides rows of trees and strips of grass there may be established whole gardens or small parks which either are open and to be crossed by all sorts of foot-travel, or are inclosed and serve only for quiet retreat. The latter enclosed spaces

are especially of great value to health. They come to be so by lessening street dust, by giving shade and by cleaning the atmosphere, and furthermore by this, that every such improvement affords opportunity for refreshment and recreation.

In addition to these, however, public parks of greater expanse are a hygienic necessity, wherein the people may take exercise in the open air. These are artificial landscapes of from 5 to 100 or more hectares in extent, which, under the titles of city gardens, people's gardens, burger parks, and the like, serve at the same time for bodily exercise (school play, football, croquet, lawn-tennis, skating, etc.), for the people's amusément and recreation.

The precise area which should be required in a city for tree planting is not easily specified. The local circumstances and means are in this respect extremely various. As a minimum it may be demanded that at least one-tenth of the city surface will be planted, and that at least 3 sq. m. of planted ground will fall to every inhabitant. The improvements outside the city limits are not included in this estimate.

The outside improvements, which ought to give the city population opportunity and inducement to further promenade or outing, are either connected pleasure grounds (*e. g.*, a natural or artificial grove) or streets and roads which will be beautified by rows of trees or landscape gardening wherever it is possible to lead to places of refreshment, or to afford a pretty outlook. The designer of a city building-plan has to provide for such hygienic arrangements in the suburbs with the greatest care.

A sixth essential of a city building-plan is, lastly, the judicious local disposition of such public or private arrangements as injure their neighborhood with regard to the health or pleasure of the inhabitants. For slaughter-houses and cattle-yards, for hospitals for the treatment of contagious diseases, and for churchyards, proper situations are to be provided. The carrying on of trades which through evaporations or noise bring danger or become burdensome is to be confined to appointed parts of the city.

II. Æsthetic Principles.

The building plan of a city in the wider sense, or the street plan in the narrower sense, ought not merely to satisfy the practical requirements of the traffic, of the building and of health; it ought also to be

laid out on æsthetic principles, *i. e.*, in such wise that it may give an impression of beauty in all its parts, or, what is the same thing, may awake in the beholder a disinterested satisfaction. As the fostering of beauty in all arts is the most eminent problem, so the beauty of the outward appearance in the art of building cities is of superlative importance. The art of city-building, which the city population everywhere comes in contact with, is more than any other branch of art practice an art for the people. If, with the cultivation of beauty, the associated influence of heart and soul be aimed at, we may anticipate from the æsthetic perfection of the building plan of a city, a rich and blessed influence upon the stratum of city population inclined to rudeness. At the same time, however, as well for the cultivated as for susceptible minds in general, it is a spring of pleasures and enjoyments. The considerations of the beautiful relate to the perfecting of the streets and squares in themselves, and to their relation to the buildings.

a. The Perfecting of the Streets and Squares.—The streets should not be too long. Too great length of street wearies the eye, wearies the spirit and awakens a feeling of discomfort. The danger of this unpleasant sensation begins as soon as the length of the straight streets exceeds 20 or 30 times their width. Should, however, a change of direction be undesirable for practical reasons, there remains the remedy against the tiresome effect of subjecting the street to variations in its width and cross-section.

For the regulation of streets, straight lines ought not to be exclusively employed. Gentle curves which conform to superficial outlines or to natural boundaries may produce fine effects in the form of the streets. It is not necessary that the two sides of a thoroughfare should be always exactly parallel; a pleasant effect may follow, from the irregular widths of streets, at the opening of squares, a junction with older parts of the city, or natural obstacles of ground. The bow-shaped avenue is preferable to the polygonal form, or strictly, a bow-like polygon of which single parts answer to the widths of the houses.

A street ought not to be conducted in straight lines over a summit; that is, convex changes of grade are to be avoided. The reason of the unbeautiful appearance of this sort of convex streets lies in the apparent sinking of the buildings, wagons and people beyond

the ridge of the street. Passing over a high point has to be accomplished by a bending of the street in plan and profile, the course of which the eye cannot follow beyond the ridge, or by means of breaking off the street at the summit. The interruption may be a vertical or a horizontal one ; a vertical in the form of a monument, a plantation, a fountain, or the like which the eye cannot see beyond ; a horizontal in the form of a crossing or dispersing place beyond which the direction of the street changes.

If the convex street is unhandsome, the concave profile creates on the contrary a special advantage. It affords to the street surface by day and by night a pleasing spectacle and may produce with artificial lights magnificent results.

The street surface ought not to be too wide, because the void does not satisfy the eye nor the mind. If the street surface cannot or should not be beautified with rows of trees and garden plots, a width is to be preferred restricted to traffic and health.

All portions of the street surface unnecessary to traffic are to be set out with ornamental plants or artificial ornaments. Rows of trees and garden spaces have been already mentioned. Artificial ornaments consist not merely in monuments, graceful statues, water-jets, flowing fountains, gate structures, arcades, and other works of architecture and sculptural art, but also in the tasteful and well-modeled improvements of requisite utility upon the streets, such as trading stalls, waiting rooms for street railways, places of convenience, columns for posters, fire-announcers, drinking stands, lamp-posts, candelabra, lanterns, street-signs, warning-boards, boxes for sweepings, enclosures, and tree-boxes. To the artistic sense and artistic gift of form, pleasure is given by all these, for the most part subordinate, objects, and thus they come to contribute to the pleasing and agreeable appearance of the street scene.

Finally, it is important in the improvement of the streets to provide for frequent change. This change should relate to street widths, the widths and arrangement of driveways and walks, the number and position of rows of trees, the artistic ornament, the garden surfaces in the streets and front yards, the kind of house-buildings (closed or open, high or low buildings). Every street, or at least every prominent street, should be handled and improved for itself individually, so that it may afford a characteristic appearance. The wearisome and

unhandsome uniformity under which so many modern streets suffer may be in this manner effectively avoided.

All the foregoing remarks upon perfecting the streets apply in greater measure to the public squares. They should not be too large, nor built exclusively on straight lines, nor have any summits; they should utilize the advantage of concave surfaces; they should be adorned with trees set out, with garden plots and artistic ornaments, so far as the traffic and the considerations in the following paragraph permit it to be done; and they should present an individual variety in their setting out.

The traffic squares decidedly require openings on all sides; their free surfaces serve the walking and driving travel. All other squares need a close-built frame of surroundings, because it is through this frame that the square is formed in an architectural sense; the wagon travel may be permitted around the border of the parks, but not across the open spaces of such squares.

b. The Relation of Streets and Squares to the Buildings.—The streets of the city are not merely for the purpose of serving the traffic, giving an opportunity for the improvement of real estate, and by their air spaces, plantations and accessories proving useful and beautiful, but they are also destined to bring our structures into agreeable position and effective grouping. The latter applies in an especial manner to monumental works of architecture and sculpture.

According to æsthetic laws, there are four different distances to be distinguished for viewing buildings and statues, viz., a distance equal to the approximate height of the work, which is specially suitable for observing the details of a structure; a distance equal to double the height, to view the whole work as a picture by itself; a distance equal to three times the height, in which the work, united with its surroundings, makes a part of the joint architectural idea, and a fourfold and greater distance, which only shows the grouping of masses and development of outlines, producing picturesque views of the city.

From which it follows, if a monumental edifice is to be erected within the ordinary street lines, the width of the street should not be less in any case than the height of the contemplated structure; but it is better to bring the street to one and a half or twice the measure. Should the latter be impracticable for the whole length of the street, the widening should occur directly in front of the structure, by

placing the structure back behind the street lines, in order to obtain front space and thus a distance of sight. Instead of setting back the structure, the corresponding place on the opposite side of the street can be set back, so that the open space is obtained on the other side of the street. In curved streets the concave side, to which the sight is always directed, is chosen for erecting monumental buildings, because more suitable than the more hidden convex side of the street.

But the appearance of a structure is more effective if in the original establishment, or the later completion of the plan of the city, the street system is so laid out that a monumental work forms the objective point (closing point) of a street, or of several streets; and furthermore, an elevated locality is assigned to such buildings. The axial and elevated erection of monumental buildings enriches and beautifies the appearance of the city, and serves at the same time a practical purpose, as it makes it easy to direct one's way in the network of streets.

We should beware of too frequently occurring faults in the axial arrangement of streets and monuments, namely, of exaggerating the distance of view, and of obstructing the traffic. According to the aforementioned æsthetic principles, the monument already begins to lose its architectural effectiveness at a distance of four times its height; there remains only the effect of picturesque masses and outlines. But these, too, lose their signification if by a very great increase of vista the scale of objects is too much reduced. Statues are, on this account, particularly unsuited to street intersections, and architectural works, as a rule, should not stand free to view at a greater distance than such as corresponds to 10 times the height. Also, a monument ought not to be of the kind to interrupt a line of traffic which would be compelled to go around the structure, in order to set forward again on the further side in the same direction as before. The monument should rather occupy the effective street termination at which a natural turning aside or separation of traffic occurs.

Still more than the shaping of streets does the improvement of public squares stand mutually related in artistic effect to buildings and monuments erected on or near the squares. The destination of squares as traffic areas, as air reservoirs, and as shaded places of recreation stands subordinate to the question how they may serve as a place

of setting up the more important works of architecture and monumental art. The erection follows so that the buildings and monuments take up a position either upon the area of the square, or they surround the square, or both kinds of erection are combined.

If the square is built up with a structure standing free all around, a space must be left open in front of the building at least of such width that it may serve as a plaza so as to offer the sufficient distance for observation. Here especially a distance equal to double the height is of importance. The other parts of the square have then merely a nearly neutral significance.

Instead of one front space, two or more are often arranged, in order —besides the front view—to bring into proper effect some other important aspects of the monument. With monuments of great extent this arrangement, which results in the division of the entire square into a group of squares, is specially judicious. In this connection care should be taken to secure the aspect of being in a closed frame to each one of the partial squares.

In a similar manner, too, should sculptured monuments, if they occupy a public square as a masterpiece, be so placed that the larger portion of the area should extend in front of the statue for its better observation, while the other parts of the square have a more restricted significance. The exceptions are such purely architectural monuments as columns, obelisks, fountains, etc., which are equally important on all sides. These may occupy the middle point of a square. Another kind of arrangement is adapted to an elongated place. It consists of a row of figures or monuments occupying the longitudinal axis, so that a masterpiece may adorn the middle point.

If the place is surrounded with several buildings, and has an open area, there arises the most distinguished creation of city construction. The most careful weighing of proportions is here especially important, in order to obtain the appropriate distances of observation. High structures come to stand at the ends, and low ones along the sides, of a place. A space of view of double the height is essential to comprehend the form of an edifice; a threefold distance is necessary, in order to enjoy a general view of a group of buildings. It does not require symmetry in a geometrical sense; but the buildings should so surround the place that an artistic balance may everywhere prevail, that the enclosure may appear complete, and that the outgoing streets may

not break up the design unfavorably. In many cases the breaks may be abolished or avoided by portals built over the street exits.

Also statuesque figures standing along the sides are suitable to complete and embellish the surroundings of the place. To every work can the just distance of view be thus afforded, while it contributes in general form to the artistic effect of the whole.

The combination plan of building upon and around the parts of a square is truly difficult, but still is accompanied by the loveliest artistic effects, if it fulfills the æsthetic considerations which govern the erection of building and monumental work in the various positions. It requires great exercise of a well-developed artistic feeling to strike the right thing. This feeling alone decides in a so-called picturesque, that is, irregular, laying out of a place and free groupings. These often occur, too, in modern, practically managed city plans where it depends upon bringing into harmony historical structures with new creations.

ABSTRACT.

I. Practical Principles.

a. The city traffic demands the laying out of radial, ring, diagonal and by streets, as well as business squares and focal points. A mere rectangular system is unfit for a street plan.

The laying out of street railways is to be regarded. The profile of the streets should be the flattest possible, but drained, the embankments not to be too high. Excavations are to be practically avoided. The width and cross-section of streets should answer generously to the amount and kind of traffic.

Also for traffic not done on the streets (railroad and water-way traffic) the layout of the city must have a care.

b. The blocks formed by the network of business streets are suitable for city construction. Sharp-angle corners are to be rounded off.

Within the blocks the property lines are to be swung into rectangular position by either voluntary exchange or legal compulsion.

The layout of the city has to provide blocks of different sizes in suitable places, such as are requisite for business operations, private houses, rented houses, stores and workmen's dwellings.

Also, blocks and parts of blocks are to be provided in suitable size and place for erecting public buildings.

c. For reasons of health, the city ground must be free from overflow, or protected; the soil must be kept dry and clean.

An underground system of sewers is indispensable to the removing of atmospheric precipitates, the domestic and industrial waste water, and human excreta.

General provision of good drinking water is necessary.

A sufficient provision of atmospheric light and of direct sunlight is to be served by a judicious orientation of the streets towards the cardinal points and a generous width of the streets; but, better still, by a rational arrangement of the habitations within the blocks. For night lighting the electric light is preferable to gas.

The providing of the city with fresh air requires, besides sufficient width of streets and size of yards, open squares in the street system and gardens in the building blocks; further, such districts as will allow only separate buildings to be erected; and, finally, shade trees on the streets, squares and separate parks. The plantations, consisting of rows of trees and garden levels, serve not merely to purify the air, but cause the city population to take bodily exercise, and afford recreation and refreshment.

The city layout has to provide special districts for industries injurious to health or annoying, or to lay down local restrictions.

II. Æsthetic Principles.

a. The elegant development of the streets requires the restriction of street-lengths, the variation of straight and curved street lines, the avoidance of convex and the preferring of concave changes of grade, the avoidance of street spaces all too wide and vacant, the setting out of the streets with horticultural and artistic decorations, and, furthermore, the individual handling of single streets, but not in a pattern-like way.

For the elegant development of places the same points of view are to be regarded. Convex shape of ground and excessive size of vacant levels are to be avoided; individuality of formation to be aimed at, and, so far as the design permits, a close-built frame of surroundings to be provided and the open spaces to be kept free from carriage roads across them.

b. For obtaining an elegant proportion between the streets and places on the one hand and the buildings on the other, the following

rules are useful: Choice of street-widths not narrower than the height of buildings; arrangement of spaces in front of important structures; preference of the concave side of streets; putting prominent structures in an elevated position and at the objective point of one or more streets, while avoiding, however, the embarrassment of traffic and exaggerated visual distances; furthermore, placing a structure upon an open square, so that a front space, or several parts of a square, suitably enclosed and of sufficient size, may be kept free for observation of the structure; placing one or more monumental buildings on or around an open place, so that suitable visual distance is everywhere afforded, the artistic equilibrium produced, the enclosure of the picture made complete, and its disintegration avoided.

Monuments of a figurative art are not to stand at the middle point of a square; this is permissible only for all-around homogeneous works of architectural art. Arranging them in rows on the longitudinal axis is seldom judicious, and standing them around the border is frequently so, and the bringing about of a correct distance for observation is necessary.

For the irregular arrangements of a picturesque kind, there is no other rule than artistic feeling.